AN INTRODUCTION TO
ENERGY CONSERVATION AND RESIDENTIAL LAND USE

FOR THE

TECHNICAL RESEARCH DIVISION

CANADA MORTGAGE AND
HOUSING CORPORATION

BY

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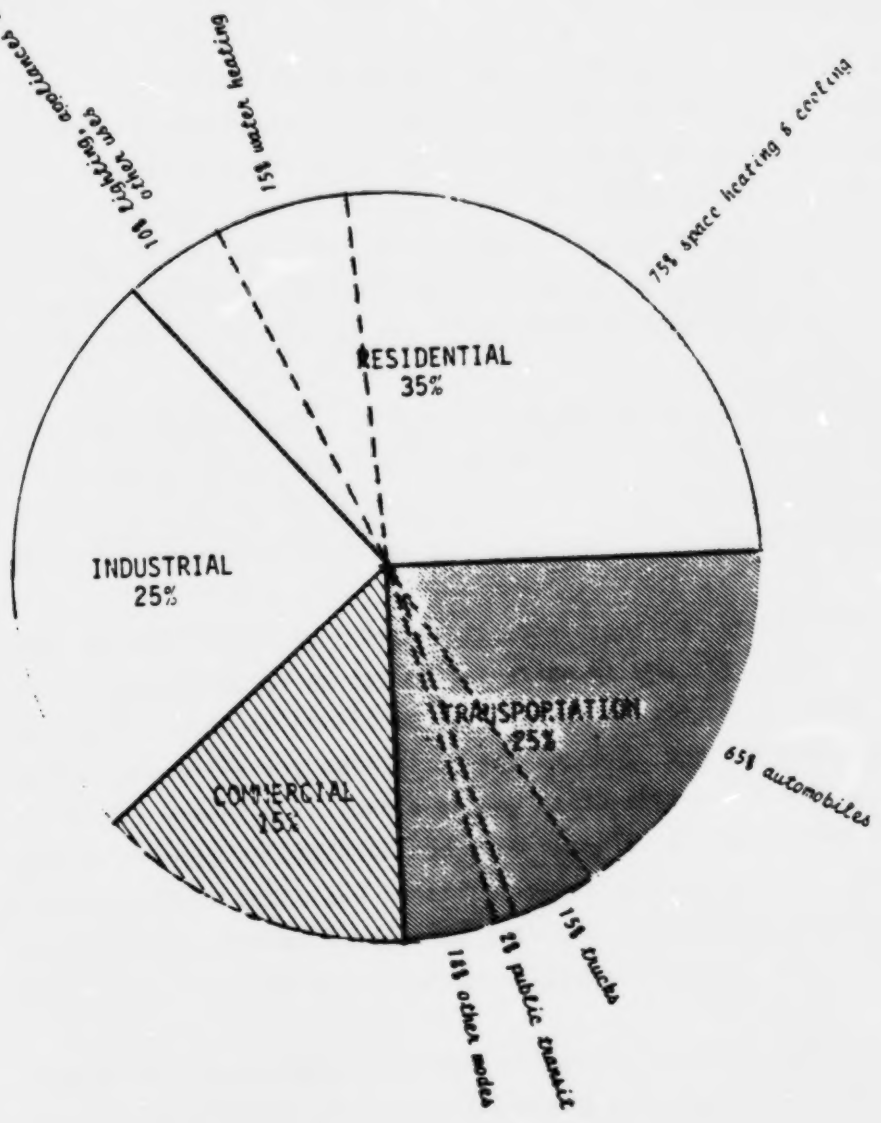
CHAPTER 1

INTRODUCTION

Figure 1: ENERGY CONSUMPTION IN A TYPICAL CANADIAN CITY



An Introduction to Energy Conservation and Residential Land Use is intended as a guide to practical energy savings in the urban living environment for planners, architects, landscape architects, developers, builders and public officials, as well as the general public. Various methods of conserving energy in residential areas are considered with emphasis on those which are cost-effective; that is, those which seem to have positive economic returns.

The focus is on energy conservation principles as they apply to residential development. Approximately 35% of the energy consumed in a typical Canadian city is associated with residential development including space heating and cooling, water heating, lighting, appliances and other basic uses. Transportation, which is closely related to the location and layout of residential areas, consumes a further 25% of the urban energy budget (Figure 1).

After setting the scene with a consideration of the Canadian and world energy situations and the potential for reducing conventional energy use, Chapter 2 presents a Canada Energy Zone Map which indicates regional energy requirements and opportunities.

Each of the following chapters is then organized to consider major approaches to energy conservation at the city, neighbourhood and residence scales of residential development. Each level relates to different sets of energy concerns and different sets of actors who most influence energy conservation. Planning and design principles are outlined, and examples are presented to indicate their costs and benefits in various situations. Where appropriate, the conclusions to sections or chapters indicate the main cost and benefits of conservation approaches.

Chapter 3, "The City", considers cities as a whole. At this level, the greatest potential for energy-savings appears to be in the transportation sector. Increasing residential densities and mixing land uses, along with modifying transportation systems,

seem to be the means to this end. The existing city fabric has a greater need for attention than future development areas, but interventions to redevelop, rehabitate, convert and infill existing areas often require public encouragement and support.

Chapter 4, "The Neighbourhood", assumes that neighbourhood energy savings will occur in both the transportation and residential energy-use sectors. Since most neighbourhood development in this country is initiated by the private sector under guidelines developed by government agencies, both the developer and government are the primary actors at this scale. Four principal energy approaches are considered: compact form and mixed land use, district heating, environmental design and solar access. These produce energy savings through reducing the energy capital required to develop a site and through reducing operational energy required for residential heating and cooling, utilities and transportation. Despite infill opportunities in existing neighbourhoods, most approaches apply to the development of new energy-conserving neighbourhoods.

Chapter 5, "The Residence", deals with energy savings at the level of the individual lot and dwelling unit, homeowner or tenant. Energy-savings related to modifications in building envelope, operation, design, siting and landscaping are briefly outlined. Both future and existing housing developments are considered.

Costs and benefits are an essential measure of the usefulness of conservation approaches. Obtaining cost and benefit information is difficult, especially at the city and neighbourhood levels, for the following reasons:

- few studies quantify overall energy savings in relation to the additional costs of energy-efficient development;

- approaches may be consciously or unconsciously biased by pre-selection: conservation approaches are often pre-selected on the basis of marketability, cost-benefit accrual, local development regulations, technical know-how or personal preference;

- various examples are often not comparable due to the use of different standards of measurement and the lack of essential information;

- assumptions behind the use of certain conservation techniques rather than others are not always explicit, and,

- the ideal results obtained in certain studies are greater than the real energy savings following a period of monitoring.

Lacking 'hard' cost-benefit data this book outlines major principles and approaches to energy conservation and residential land use, and attempts to provide the reader with an understanding of the relative magnitudes of the costs and benefits of major principles and approaches.

1. SETTING THE SCENE

In order to "set the scene" for the following discussion of energy conservation and residential land use, consideration is given to national and regional strategies for dealing with the effects of the world "oil crisis". In this context the Canadian and world energy situations are briefly described, followed by a more detailed consideration of Canadian energy consumption patterns and options.

Although Canada is facing a problem of oil availability and price, she is favourably endowed with most other conventional and alternative energy resources. As a net exporter of energy - coal, natural gas, uranium and hydroelectricity - this country has the wherewithal to achieve energy self-sufficiency through oil substitution and energy conservation, while developing alternative energy sources for enduring energy security. This requires investment in oil substitution and energy conservation as well as development of renewable energies. Energy conservation has the potential to save large amounts of energy in Canada with positive economic and social benefits.

The potential for energy self-sufficiency in Canada shows regional imbalances: the three Western Provinces have energy surpluses while the rest of the country is in an energy dependent or energy deficit position. While this picture is changing as a result of energy resource development in the North and East, imbalances in energy potential will likely remain. The potential for alternative energy exploitation also varies according to climate and geography. Regional energy requirements and energy opportunities are synthesized in the Canada Energy Zone Map presented in this chapter.

Despite regional variations which affect energy prices, the energy expenditures of most Canadians in similar income groups are comparable. The gap in spending between different income

groups in the same region is more pronounced. Government programs may be required to help those who are unable to afford increased energy prices and who have already invested to their limits in energy conservation.

2. WORLD ENERGY PROBLEM

The world energy problem is a problem of oil availability and price. Between 1960 and 1980 world oil consumption tripled while relative use of oil as an energy source doubled to meet two-fifths of world primary energy demand. This growth, coupled with a decline in United States supply capacity, placed a heavy burden on world oil markets.

World oil prices declined steadily between the 1940's and the 1960's and remained stable at approximately $3.00 per barrel until the early 1970's, despite moderate inflation. After 1973, the Organization of Petroleum Exporting Countries (OPEC) replaced multi-national oil companies as the main force in world oil production. OPEC is a cartel formed to obtain higher returns for oil through supply management and decree. World prices rose beyond $38.00 per barrel in 1980 producing a major economic crisis.

Oil importing countries are moving to reduce their dependence on oil but the change will not be easy. Careful choices are required regarding other conventional energy sources; for example, heavy reliance on coal or nuclear power sources carries environmental, safety and health concerns.

Alternative energies are not yet sufficiently developed to take up the slack in energy supplies and, while conservation efforts are proceeding, major reductions in energy consumption will take time as behaviour patterns and industrial structures based on inexpensive and plentiful energy are modified.

Figure 2: ENERGY SOURCES (%)

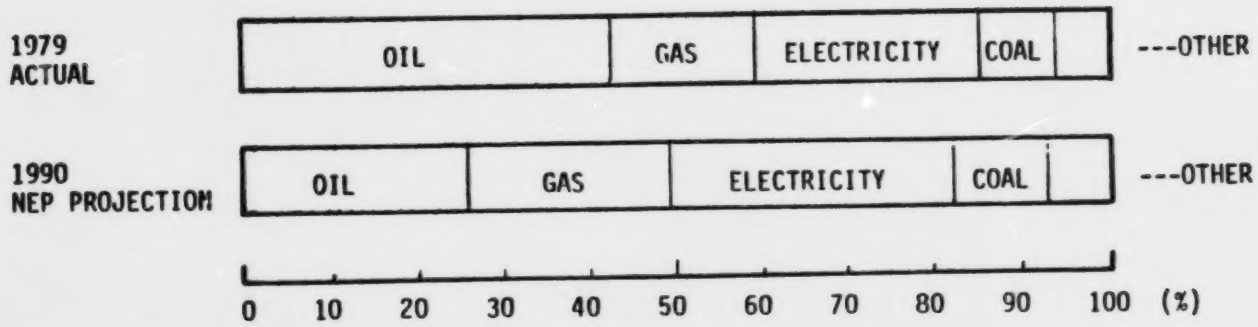
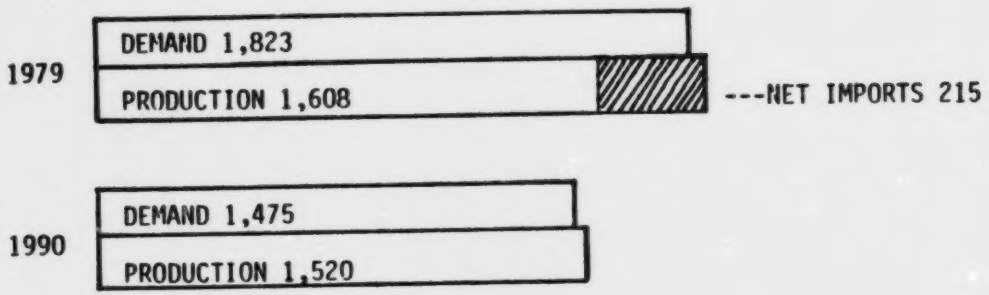


Figure 3: CANADIAN OIL SUPPLY AND DEMAND (Mb/d)



Source: Energy, Mines and Resources Canada, 1980.

3. CANADIAN ENERGY PROSPECTUS

Canada, a net exporter of energy, has been dependent on imported oil since 1976. Approximately one-third of Canadian oil consumption is imported. Yet Canadians produce enough energy in other forms, such as hydroelectricity and natural gas, to displace all oil imports and still have substantial resources for export. Oil substitution and energy conservation are the cornerstones of a national energy strategy aimed at a rapid reduction of reliance on oil and a gradual conversion to alternative energy systems such as solar, wind and biomass (See Figures 2 and 3). This strategy should lead to energy self-sufficiency and security of energy supplies.

The National Energy Program 1980 (NEP) recommends:

1. improving oil use efficiency;
2. using surpluses of electricity, natural gas and other fuels to overcome the deficit in oil in the coming decades;
3. developing the conservation resource, and
4. developing alternative energy technologies including biomass, solar, wind, geothermal, tidal and nuclear fusion.

Improving oil use efficiency means the replacement of heavy fuel oil in industrial applications and the upgrading of heavy oil stocks to lighter products such as gasoline, aviation fuel, diesel fuel, home heating oil and petroleum feedstocks. This involves the modification of existing refineries and the development of new refineries to reduce to a technical minimum the production of heavy fuel oil in Canada.

Improving oil use efficiency also means development of the heavy crude oils of Saskatchewan and Alberta which required enhanced recovery processes.

Federal grants are being offered to consumers to substitute heating oil with natural gas or electricity. The NEP intends to reduce oil use by 90% in the residential, commercial and industrial categories by 1990. Transportation sector consumption, however, will be more difficult to cut back.

Natural gas prices are rising more slowly than the price of oil, remaining at a level of 75% or less of the oil price, in order to encourage conversion. Natural gas distribution systems will be expanded to Vancouver Island and the Atlantic Provinces, and East Coast gas prices will match those in Ontario and Quebec.

Canada's conservation resource is large because traditionally inexpensive energy did not put a premium on energy efficiency. Paradoxically our past inefficiency means Canada now has a substantial conservation energy potential which can be easily and economically exploited. In other words, by reducing energy use now, Canadians will have more energy to use in the future.

The implementation of most energy conservation measures depends on the economics of the required investment. As the price of energy increases relative to other goods and services, more measures will become economical and those which are now viable will have shorter payback periods.

Energy conservation has the following major economic and social benefits, even where the implementation of conservation measures are not immediately cost-effective:

- conservation can have a substantial impact on reducing national energy demand. The Federal Government supports conservation programmes because they represent the most immediate and inexpensive means to self-sufficiency. Even convincing Canadians to turn down thermostats, turn off lights and drive smaller cars will produce substantial energy savings;

- conservation can minimize Canada's reliance on oil;

- conservation can create jobs and new opportunities for small businesses, and the benefits would be broadly distributed across the country;

- conservation and alternative energy technologies can assist in maintaining environmental quality in contrast to the effects of fossil fuel extraction and use, and the environmental degradation associated with hydro projects, and

- conservation can buy time, allowing Canada to stretch fossil fuel supplies and prepare for a lower consumption lifestyle based on alternative energy sources.

Canada's alternative energy strategy is to develop an inexhaustible, environmentally benign and flexible energy system controlled by Canadians and recognizing regional diversity. Energy will be derived from renewable sources including hydroelectric, solar, wind, biomass, geothermal, tidal, and nuclear fusion.

Oil will continue to play an important role in Canada's energy mix for a considerable time, since this country already has the infrastructure for oil production, distribution and consumption.

4. END USE

Residential, including farm, energy use is 20% of the Canadian total (EMR, 1979). Within urban areas, however, the residential sector accounts for a higher proportion of energy use.

Although residential energy use as a percentage of all urban energy use varies between cities depending on their climate, industrial mix and form, Canadian residential consumption is typically 35% of total urban energy consumption (Figure 1). Approximately 75% of residential energy consumption goes toward space heating, 15% toward water heating and 10% toward other basic uses such as lighting and appliances.

The energy consumption differences between average residential households in different cities are not as pronounced as would be expected given climatic, economic, geographic and other factors. This is, in part, due to federal government equalization of fuel energy costs, especially in the Atlantic Provinces, but there seems, as well, to be a certain accepted level of energy expenditure for home heating which is similar from one end of Canada to the other.

Effect of Lifestyles

Individual lifestyles in society affect the general pattern of energy use. In Canada, the "Baby Boom Cohort", a large bulge in the population profile, entered the high consumption age group of 15 to 30 years in the 1970's. This group, which had high expectations about living standards and an interest in present consumption, caused an increase in per capita energy use.

Although attitudes do not change easily, increasing energy costs tend to modify energy consumption trends.

The importance of energy-saving home features to present home buyers is most evident when compared to the appeal of traditional new home amenities (Land Use Digest, 1981). Asked to rate the importance buyers place on a variety of home features, builders ranked the following features as extremely important:

attic insulation	67%
wall insulation	63%
kitchen appliances	49%
central air conditioning	42%
storm windows	43%

Kitchen appliances and central air conditioning, long regarded as the most popular new home features have now been replaced by attic and wall insulation.

At the bottom of the buyer's shopping list were other traditional amenities such as:

fireplaces	22%
patios	18%
landscaping	15%

In a survey of homeowners, brokers, and appraisers, (Land Use Digest, 1981) 83% of the homeowners responding said well-insulated houses were worth more at resale; 66% of brokers and 78% of appraisers regarded such homes as worth more. Brokers estimated that a well-insulated home would be worth an average of 9% extra; appraisers estimated that it would have a resale bonus of 5%. Energy conservation in housing has become a marketable asset.

According to Miloff (1980) the lifestyles of some Canadians are already changing to reflect the need to conserve energy. Lifestyle changes among low income families and senior citizens have sometimes reduced their energy consumption levels to very small absolute amounts. Further rises in energy prices would not induce greater cutbacks but only greater hardship.

Most affected by energy price increases are senior citizens in energy inefficient homes, low income tenants in bulk-metered housing and large families with greater than average space heating, water heating and transportation requirements.

While higher income families seem at first to have invested more heavily in energy conservation measures to reduce residential space heating requirements, the real difference between income groups is only slight when bulk-metered low income tenants are omitted. Bulk-metered households have the least ability to control their heating expenditures and the least incentive to cut back on energy use, since they do not have immediate positive feedback through lower energy bills. Low income families who are not bulk-metered generally spend larger proportions of their

incomes on energy conservation than higher income families. With incentives to conserve, low income families have also cut back more in their use of appliances and energy consumption for water heating. They are more likely to have added insulation blankets or reduced temperature settings on hot water tanks than higher income groups.

Approximately 40% of low income Canadian households own cars (Miloff, 1980) and they pay a considerably larger proportion of their incomes than other groups on transportation energy, especially when living in the suburbs. A greater proportion of low income families have taken steps to reduce gasoline expenditures than have middle income families. Low income families are driving less, using public transit or forming car pools.

5. CANADA ENERGY ZONE MAP

The wide range of energy requirements, opportunities and constraints in Canada must be understood so that the least expensive and most appropriate energy systems and energy conservation measures will be developed in every region of the country. A systematic approach to regional energy use and conservation would help reduce the burden of energy expenditures on all income groups.

The Canada Energy Zone Map (inside back cover) illustrates 28 energy zones differentiated by climate, geography, energy supply and energy potential. The map is a systematic approach which indicates energy requirements and energy opportunities in each zone, and serves as a guide to the use of appropriate energy sources and energy conservation measures in different regions of Canada. The following sections outline how to use the Energy Zone Map.

The Energy Zone Map can be used to compare the opportunities and constraints of different energy zones, allowing an example of energy conservation in one zone to be considered in the context of other zones. The Saskatchewan Energy Showcase Homes, with high insulation values and solar features, can be used as an example of how this works. Since Saskatoon is in Zone 24, "Parkland", with a COLD to VERY COLD climate and LOW to MEDIUM solar potential, the Energy Showcase Homes should fit the climate and solar potential of Zone 6, "Mid-Canada", and Zone 17 "Northern Prairie", which have characteristics similar to Zone 24. They will also fit most MODERATE to COOL climates with MEDIUM to HIGH solar potential but would be overdesigned for a WARM zone and inappropriate for a zone with no solar potential.

The Energy Zone Map is designed to fold out of the book and the energy zones are designated by geographic names as well as numbers, for easy reference. Each zone is described by physiographic region and climate; existing energy supplies, and future energy sources and potential.

The "Legend" with the map provides the qualitative or quantitative parameters for the descriptions of climate (WARM - ARCTIC) and energy potential (HIGH - LOW). These are outlined in detail below.

Climate and Energy Requirements

Residential energy requirements and conservation measures are largely determined by local climatic factors. Canada's climate has large differences: ranging from the Atlantic Provinces, with cold winters, mild summers and moderately high precipitation throughout the year; through Southern Ontario, with hot summers due to the invasion of tropical air masses; across the Prairie Provinces with cold winters, hot summers and moderate to little precipitation; to the West Coast with moderate temperatures and high precipitation all year. The northern areas of the Provinces and the southern areas of the Territories have long cold winters

and short mild summers; while northern areas of the Territories have very cold winters, cool summers and extremely dry climates .

In order to generalize Canadian climatic regions and to more easily consider United States examples in the context of Canadian climate, a descriptive system based on mean annual heating degree days is used to differentiate between energy zones in terms of climate and heating requirements. This does not account for humidity, which influences the perception of "cold" or "hot" at different temperatures.

Mean Annual Heating Degree Days

The heating requirements of the zones are assessed in terms of heating degree days (HDDs). For the traditional housing, the number of HDDs accumulated in a given day is the difference, in degrees Celsius, between the mean temperature for that day and an 18°C base temperature (the outdoor temperature below which auxiliary heating is assumed to be required). When the mean temperature for a winter day is -5°C, for example, 23 HDDs will be accumulated for that day. Mean annual heating degree days are the total HDDs through the year.

The outdoor temperature at which auxiliary space heating would be required in low energy housing typically ranges from -10°C to 10°C, depending on factors such as solar gain, internal gain and basement heat loss. Although traditional HDDs cannot be used to calculate heating loads on low energy houses, they do provide a rough comparative measure of heating requirements in different parts of Canada. This, in turn, will influence the design of low energy housing in the different zones.

The map descriptions of heating requirements range from LOW to HIGH, corresponding to climates from WARM to ARCTIC. This range is indicated by the cities and towns in Table 1.

TABLE 1
CLIMATIC ZONES FOR CANADIAN CITIES AND TOWNS

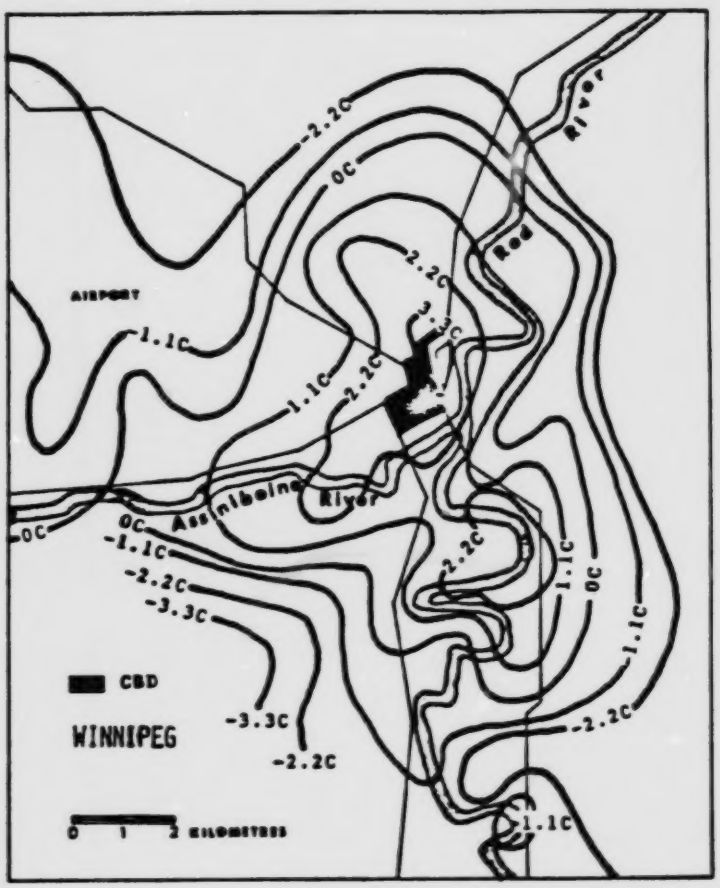
Climate	Mean Annual HDDs	City or Town
WARM	3000 - 4000	Windsor, Ontario
		Vancouver, British Columbia
MODERATE	4000 - 5000	St. John's, Newfoundland
		Halifax, Nova Scotia
		Fredericton, New Brunswick
		Montreal, Quebec
		Toronto, Ontario
		Nelson, British Columbia
COOL	5000 - 6000	Winnipeg, Manitoba
		Regina, Saskatchewan
		Calgary, Alberta
		Edmonton, Alberta
COLD	6000 - 7000	Saskatoon, Saskatchewan
		Whitehorse, Yukon Territory
VERY COLD	7000 - 9000	Yellowknife, Northwest Territories
ARCTIC	9000 - 12000	Inuvik, Northwest Territories.

Most Canadian cities are in WARM to COOL climate zones with MEDIUM heating requirements.

Heating Requirements and Energy Expenditure

Heating requirements are only one of a number of factors affecting annual household energy expenditure. Regina, Saskatchewan, with nearly double the mean annual heating degree days of Vancouver, British Columbia, has a lower average energy expenditure per

Figure 4: TEMPERATURE DEVIATIONS ASSOCIATED WITH HEAT ISLAND IN WINNIPEG



Source: Lawford, 1979.

household. The mean daily January temperature in Regina is -15°C; in Vancouver, -2.5°C. Lower energy prices and different building standards for insulation and windows are among the factors in Regina's favour. The largest annual energy expenditure per household is in St. John's, Newfoundland, which has less than 5,000 mean annual heating degree days (MODERATE), and the smallest is in Edmonton, Alberta, with approximately 6,000 mean annual HDDs (COOL).

Summer Cooling Loads and Urban Microclimates

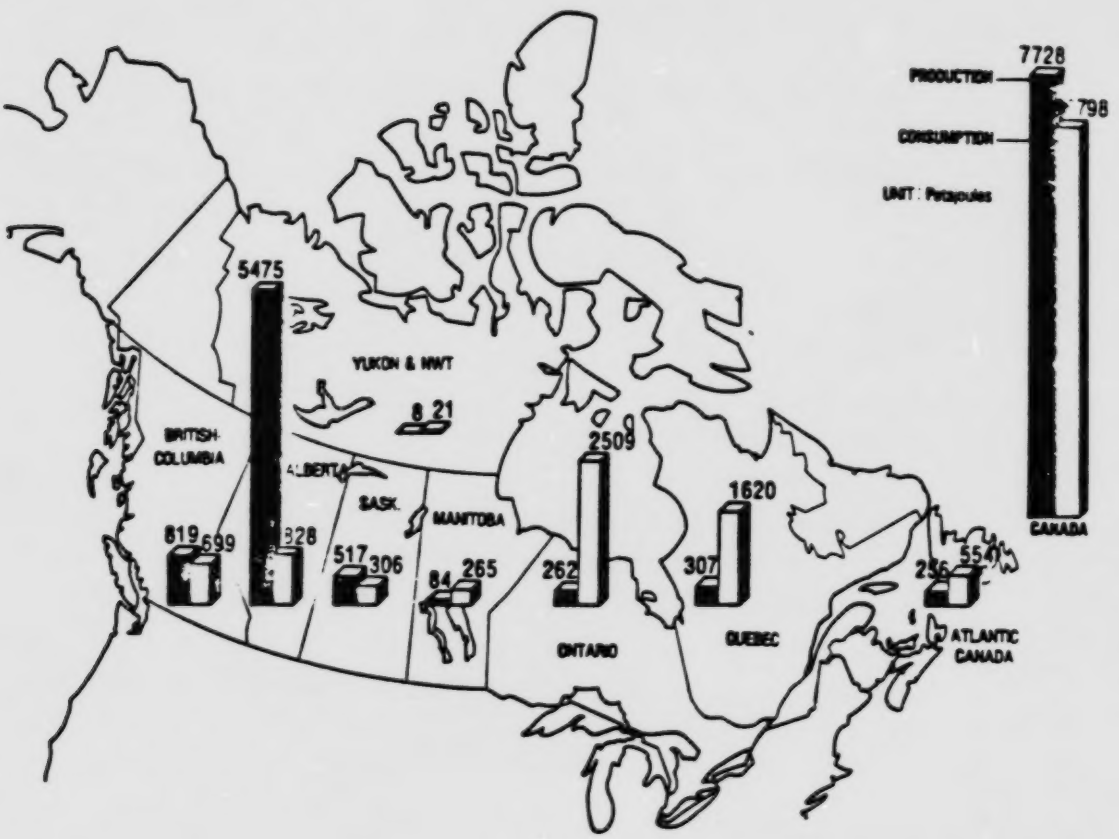
Summer cooling loads also effect annual household energy expenditure. The humidex, determined by taking the dry bulb temperature and adding a fraction of the vapour pressure, is an important variable in assessing requirements for air-conditioning. Winnipeg, with a mean daily temperature in July similar to Toronto and Montreal, has less requirement for air conditioning than the eastern cities due to the drier Prairie climate.

Large metropolitan centres tend to modify the regional climate, decreasing heating requirements in winter but increasing cooling requirements in summer (Figure 4). Urban microclimates are related to factors such as lower albedo - the amount of sunlight reflected from surfaces rather than absorbed, - lower wind speed and higher runoff co-efficient.

Conventional Energy Sources and Potential

About half of Canada's energy requirements are supplied by liquid hydrocarbons (crude oil and natural gas liquids), but while the three Western Provinces are net exporters of hydrocarbons, the remainder of the country relies heavily on imports (Figure 5). Only Alberta is self-sufficient in oil. Eastern and Northern Canada depend on imported oil for fuel and electricity. While both regions have future energy potential, they both have immediate supply problems.

Figure 5: PRIMARY ENERGY PRODUCTION AND NET ENERGY CONSUMPTION BY REGION IN CANADA DURING 1978



Note: Data for Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island are aggregated as Atlantic Canada for reasons of confidentiality in industry reporting. Energy statistics for the Yukon and Northwest Territories are also aggregated. Otherwise the regional breakdown is by province.

Source: Statistics Canada, 1980.

The Canada Energy Zone Map describes the potential in each energy zone for conventional energy sources such as oil and gas, coal, uranium and hydroelectricity. The potential for air-to-air heat pumps is also described. These HIGH, MEDIUM or LOW levels are based on qualitative parameters set out in the map legend. Generally, the levels are as follows:

HIGH: refers to a significant resource with widespread exploitation in the energy zone;

MEDIUM: refers to a less significant resource or a zone of major resource exploration; and

LOW: refers to a zone with potential for an energy resource, or with minor exploitation of a resource.

Alternative Energy Sources and Potential

The potential to exploit alternative energies varies substantially from region to region. Alternative energy strategies must be more highly tailored to specific zones of the country than have past conventional energy policies. Eastern and Northern Canada have pressing claims for attention.

Projects using alternative energy sources are underway across the nation, including:

- passive solar design in subdivisions from the Atlantic Provinces to British Columbia;

- developing vertical axis wind power systems for the Magdalene Islands and the Arctic;

- using biomass for district heating and power production in Montreal and Toronto;

- developing a geothermal power plant at Meager Creek, British Columbia; and

- developing Bay of Fundy tidal power.

Ontario seeks to increase energy self-sufficiency to 35% by 1995 using uranium, coal and peat fuels, and alternative energy sources such as solar, wind, and biomass; in addition to hydro-electric power. British Columbia is developing a coal-fired thermal power plant at Hat Creek and a geothermal power plant at Meager Creek, in addition to new hydroelc-tric projects, to take up the slack in energy supply. Other provinces also have energy strategies to best utilize available conventional and alternative energy sources.

The Canadian Energy Zone Map describes the potential in each energy zone for alternative energy sources, includng solar, biomass, geothermal and tidal. These HIGH, MEDIUM, or LOW levels are based on quantitative parameters set forth in the legend.

Solar Energy Potential

Solar energy potential in the energy zone is measured in terms of annual mean daily solar radiation expressed in Langleys, a Langley being equivalent to 11.6 watthours/m^2/day. Across the most heavily populated parts of Canada the solar radiation over the year averages about 300 Langleys per day. This means that one square metre of horizontal solar collector would receive about 3.5 to 4.0 kilowatthours of radiant energy per day in this region. (This can be compared to one litre of heating fuel which delivers about 10 KWh of energy). Only a portion of this energy is captured by passive solar systems.

Canada compares favourably with most countries of the world in terms of average solar radiation received, but this average value is less important than the seasonal distribution of solar energy.

The majority of solar energy is received during the long, sunny, summer days and considerably less during short winter days. Thus, the peak in energy supply is opposite to that of space heating demand. Seasonal thermal storage is both costly and inefficient. This should not be taken as an indication that solar energy will have a negligible role to play in a new energy mix. Canadians will simply have to use solar energy in those applications which are best matched to the availability of the resource.

Wind Energy Potential

Wind energy potential in the energy zone is measured in terms of annual average wind energy density at 50 metres above the ground, expressed in watts per square meter. The areas in Canada with the best wind regimes are the Eastern Arctic, Atlantic Canada, northern Ontario and Quebec, the southern Prairies and parts of British Columbia. Coastal British Columbia is one of the areas of greatest wind energy potential and in the mountainous parts of British Columbia there are many sites where winds are funnelled in a way which makes them ideally suited for power generation.

Biomass Energy Potential

Biomass energy potential in the energy zone is measured by biomass productivity expressed in tonnes per hectare per year. This does not account for resource quality, however, or the ability to harvest or transport biomass.

Geothermal Energy Potential

Geothermal energy potential in the energy zone is expressed qualitatively according to the existence of volcanic belts or thermal springs, or areas where the natural heat of the Earth close to the surface is above 80°C. Zones of HIGH potential are found in the areas of geologically recent volcanism in British Columbia and the Yukon; zones of MEDIUM potential are found in

areas of the Western Canada Sedimentary Basin underlying the Prairie Provinces, where enough useful energy might be recovered to offset the recovery effort.

Tidal Energy Potential

Tidal energy potential in the energy zone is expressed in terms of the potential for a major tidal power site. Observatory Inlet near Prince Rupert and the Bay of Fundy have the only potential sites in Canada.

Use of the Energy Zone Map in City, Neighbourhood and Residential Planning and Design

The Canada Energy Zone Map is a systematic approach to energy use and conservation which can be used as a guide to regional decisions on oil substitution, energy conservation and the development of alternative energy technologies. The map helps illustrate the way local energy needs and opportunities relate to city, neighbourhood and residential planning concerns. To demonstrate the use of Energy Zone Map, three different energy zones are examined, as follows:

Zone 1., Eastern Arctic/Labrador

The Eastern Arctic/Labrador Zone (Frobisher Bay) has a COLD to ARCTIC climate with a VERY HIGH heating requirement (6,000 to 12,000 HDDs). Low energy housing requires substantial additional energy to maintain the internal comfort zone. Low, massive multiple-family buildings are an ideal housing form in this extremely cold, windy environment with very little winter sun. Settlements are designed for enclosed activity and building masses shelter outdoor areas from high winds. Since the sun is only above the horizon for short periods during the winter, if at all, the wind, with intensities of 700 to 900 watts per square meter and a HIGH energy potential, is the only readily available alternative energy source. The use of vertical axis windmills as

a source of electricity and heat is being explored in the Eastern Arctic/Labrador Zone. District heating is not new; heat is generally transferred along with other services in utilidors. Like buildings, these must be raised above or insulated from the ground in permafrost areas. Today district heating is based on imported oil; in the future offshore oil and gas, or uranium from this zone may provide district heat and power through cogeneration.

Zone 9, South Central Canada

South Central Canada (Toronto) has a WARM climate (3,000 to 4,000 HDDs) with LOW heating requirements. Low energy housing requires little or no additional heat during the heating season. Present heating requirements for conventional residences are met with imported oil and natural gas, hydroelectricity and nuclear. These will continue to be important energy sources. In addition, South Central Canada has HIGH potentials for air-to-air heat pumps and solar energy, and a VERY HIGH biomass potential.

Decisions about city and neighbourhood planning in this context depend on residential energy use. Efficient furnaces maintain the competitiveness of natural gas for home heating, while air-to-air heat pumps provide an efficient means of converting electrical energy for both heating and cooling. Passive solar housing may be cost-effective in this energy zone but requires careful planning of neighbourhoods and housing units to ensure optimum efficiency. Like passive solar housing, low energy housing needs little or no additional heat during the heating season. Combining low energy and passive solar designs, however, reduces the efficiencies of both, causing excessive heat build-up on sunny winter days. Biomass energy sources, including garbage and oil, gas, coal and nuclear energy sources can be used for cogeneration of power and heat for district heating in this zone.

District heating provides cheap, low-grade heat at reasonable costs for housing which is not thermally efficient. District heating systems affect the form of cities, neighbourhoods and residences, since they are most effective in conjunction with compact, low rise development and high thermal densities (large heating requirements per area). Combining district heating with low energy or solar housing again reduces the cost-effectiveness of both systems. The decision to use a particular residential energy system in this zone should depend on the following factors:

- the thermal density of the development;
- the availability or potential to exploit the energy source;
- the overall cost effectiveness.

Zone 11, Southern Prairie

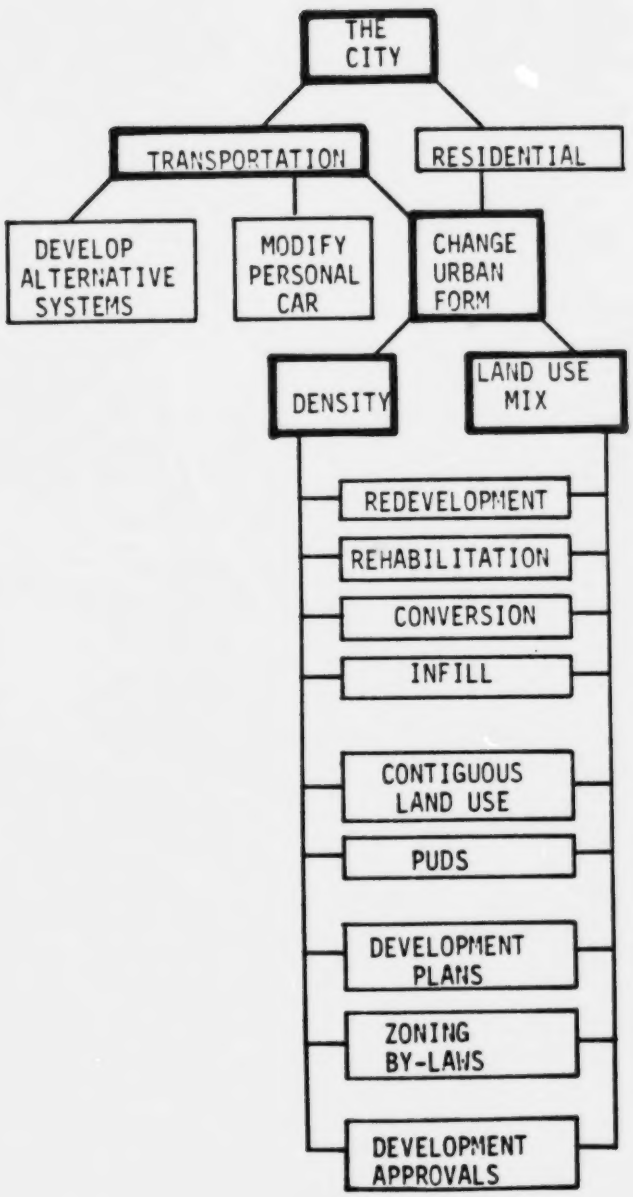
The Southern Prairie Zone (Regina) has a COOL climate with a HIGH heating requirement. Combining low energy residential design with passive solar design may be worthwhile in this zone, especially if the cost of direct gain passive solar heating is minimal. Care must be taken to reduce the cooling effect of winter winds through neighbourhood planning. The Southern Prairie Zone is virtually self-sufficient in coal, oil, and natural gas, giving these energy sources a competitive edge. Natural gas is especially favoured for residential space heating. In compact communities with high thermal densities, district heating based on coal, oil or natural gas cogeneration is a viable alternative. Biomass only competes with fossil fuels in special cases; for example, near major food processing plants. Similarly, wind energy is only attractive in certain areas as a supplier of mechanical power, electricity or direct heat. Biomass potential is VERY HIGH and wind potential MEDIUM to HIGH in the Southern Prairie Zone, but the cost of utilizing other fuels for residential space heating is less.

In every energy zone economics will set priorities, not the energy potential of a conventional or alternative energy source. As fossil fuels become more scarce and costly the viability of alternative energy sources will improve. This is already becoming apparent with the development of tidal power in Nova Scotia and geothermal power in British Columbia; use of wind power in the Northwest Territories and district heating fuelled by garbage in large urban centers in Ontario and Quebec.

CHAPTER 3

THE CITY

Figure 6: THE CITY LEVEL



1. CITY LEVEL APPROACHES

The most significant variables affecting energy conservation and residential land use at the city level are transportation and urban form. While residential energy consumption is significantly reduced by neighbourhood and residence-level conservation approaches; transportation energy consumption is most affected by city-level approaches (Figure 6). Since more than half the household energy expenditure of the average Canadian household is for the family car, reductions in transportation energy use will significantly affect household budgets.

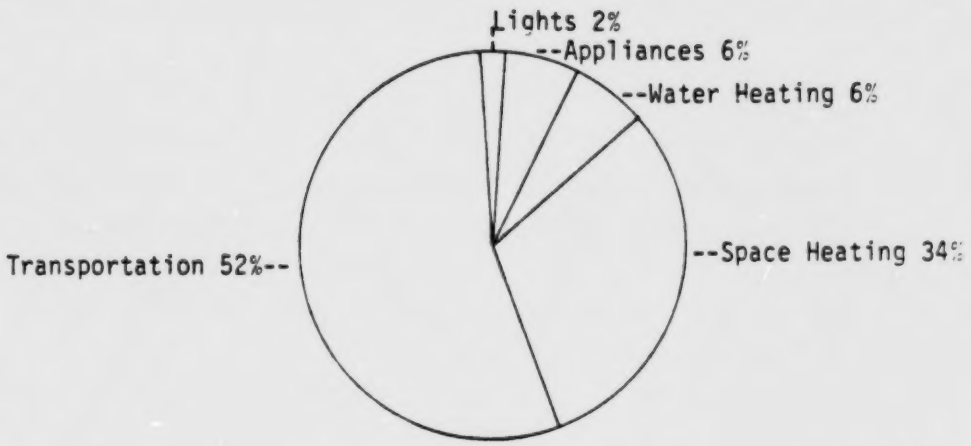
Increasing density and mixing land use will conserve transportation energy by improving public transit efficiency and reducing travel distances, and residential energy through more energy-efficient building forms. Other approaches which conserve energy in urban transportation include developing major new transportation systems and the means of enticing people to them, and improving the efficiency of the private car.

2. TRANSPORTATION AND URBAN FORM

An estimated 20% to 30% of Canada's secondary energy consumption can be attributed to transportation. The automobile alone accounts for 65% of this consumption. Putting this in the context of residential energy use is an Ontario Ministry of Housing study (1981) which found that 52% of a household's energy requirements are for the family car (Figure 7).

These figures relate to the key role played by the automobile in past and present Canadian society. Residential development has traditionally centered on the single-family detached house. The affordable automobile provided the means for travelling longer distances to work, shopping and other activities, enabling cities to expand further into the countryside to meet the housing demand. In the past, public officials in some North American cities actually promoted suburban development to alleviate congestion resulting from the increased popularity of the automobile.

Figure 7: HOUSEHOLD ENERGY USE



Source: Ontario Ministry of Housing, 1979.

Inexpensive fuel sources supported the private car-commuter lifestyle by keeping travel costs within an affordable range for most segments of society.

The low density urban form which developed as a result of the private car, single-family detached housing, leapfrogging development and inexpensive, plentiful energy supplies is best described as "sprawl". Sprawl requires more energy capital to develop and more operational energy to maintain than higher density development. Sprawl requires more energy for the construction of buildings, roads and utilities; more energy for the movement of people, goods and services and more energy for the operation and maintenance of roads and utilities, than higher density development. Wilbur Smith and Associates (1980) noted that energy savings as high as 50% can be realized if higher density development, particularly multi-unit, low-rise structures, (67 du/ha to 94 du/ha) replace sprawl.

Sprawl is and will continue to be an attractive and marketable urban form despite increasing energy costs and questionable supplies.

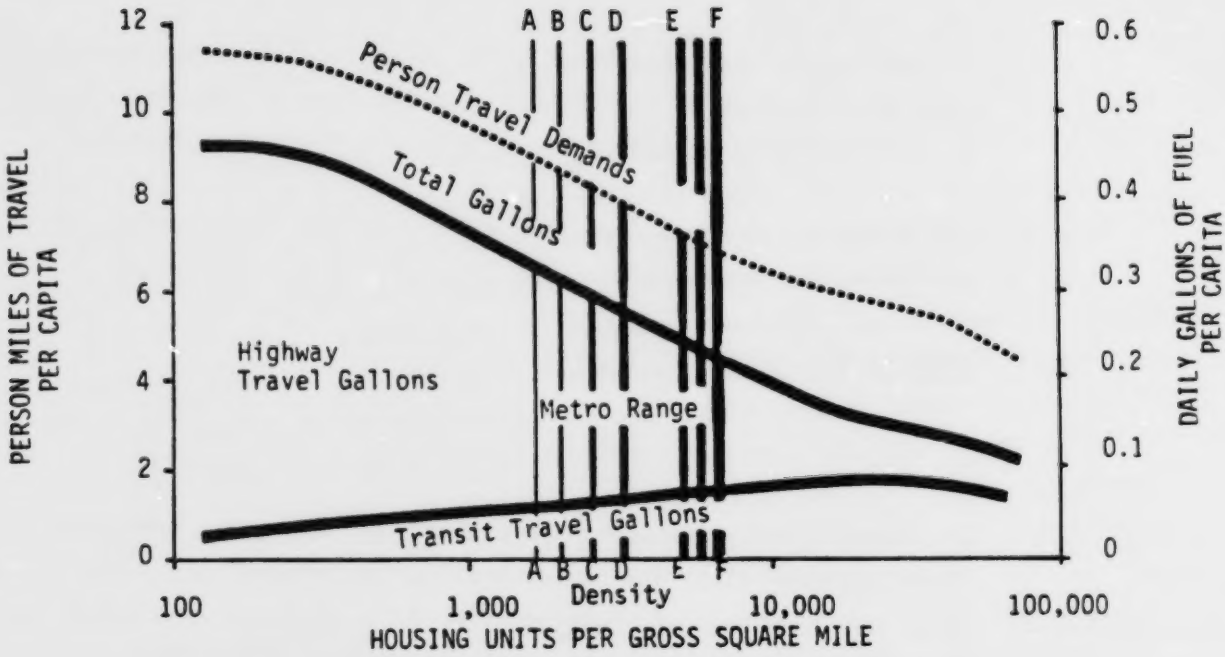
Transportation energy consumption is primarily associated with urban form and use of the private automobile. The decision to use the personal car was found by Middleton Associates (1979) to be based on factors such as the average trip length, trip frequency, trip energy consumption, and other modes of transportation available. The results confirmed that automobile use is greater in areas further from the Central Business District (CBD) where origins and destinations are more widely dispersed, and the probability of selecting public transit for the journey to work is greater in areas near the CBD and areas with higher densities. These findings are significant since the automobile is primarily used for work travel and occupancy levels are lowest during the work trip (Metro Toronto Planning Department, Metro Cordon Count Program, 1977)

Although emphasis has thus far been placed on the energy savings achieved through reducing automobile use, three scenarios can be identified which reduce overall energy consumption in the transportation sector. The first would alter urban form, through changes in density and land use mix, to make alternative transportation modes attractive. The altered urban form would be compact, with multiple centers of activity. Carefully managed redevelopment, rehabilitation, conversion and infill in existing areas and development controls in new areas would minimize sprawl, strip development and underutilized land. Multi-unit, low-rise densities in most areas would be sufficiently high to make public transit viable. Places of work, shopping and recreation would be well related to residential uses, transportation networks and each other. Mixed use centers would be clustered along transit corridors, and larger complexes in the multiple urban centers would incorporate a wide range of activities to mutual advantage. The second scenario, assuming the greatest difficulty lies in getting people out of their cars, would require the provision of convenient alternative modes of transportation and the elimination of measures which favor or encourage automobile use. Once the automobile was relegated to a subsidiary role urban form would develop along conserver lines. The third scenario, stressing that - despite increasing fuel costs and disincentives - a reduction in personal automobile use is unlikely, would devote time and effort to finding alternative fuel sources and making cars more energy-efficient. Changing urban form to reduce average travel distances would help make cars more energy efficient.

Attempts are being made to implement all of these scenarios to various degrees, but the emphasis in this study will be on the ways in which urban form can be altered to facilitate the change to more energy efficient transportation modes; reduce trip time and length, and reduce the general propensity to travel.

The principal means to these ends are the following:

Figure 8: DEVELOPMENT DENSITIES VS. TRAVEL AND FUEL CONSUMPTION
(weekday)



AA-SCAR.	1,681.7
BB-ETOBICOKE	2,022.9
CC-NORTH YORK	2,624.5
DD-EAST YORK	3,008.0
EE-YORK	5,769.5
FF-CITY OF TORONTO	6,383.6

Source: Wilbur Smith and Associates, 1980.

- increasing urban densities to levels which would make more energy-efficient transportation modes, such as public transit, van-pooling, bicycling and walking, viable, and

- mixing land uses to reduce trip time and length for work, shopping and recreation. Encouraging work at home, one kind of mixed use, would reduce the propensity to travel.

Generally, the costs and benefits of alterations in urban form will vary as a function of the current size and form of the urban area, as well as climatic, economic, cultural and historical factors.

The following sections, consider principles and examples related to increasing density and mixing land uses at the city scale.

3. ENERGY CONSERVATION PRINCIPLES

Density

Increased density results in more people per area, and generally lower transportation and residential energy consumption. The principal advantage of higher density is a reduction in the average trip length by decreasing the distance between origin and destination. The Metropolitan Toronto Area Transportation and Energy Study prepared by Wilbur Smith and Associates in 1980 (Figure 8), found that as housing density increased ten-fold from 3.9 to 39.0 dwelling units per hectare, weekday vehicle travel, measured in person miles per capita, decreased by 40%.

When a city grows in population and physical size, average trip distance lengthens. The World Bank (1976) has postulated that, for a given population density, trip distance increases roughly in proportion to the square root of the radius of the city. For example, if a city grows in population from one to two, four, and then eight million people, with a constant density, average trip distance may be expected to increase from its initial level by roughly 20, 40, and 65 percent respectively.

Sewell and Foster (1979) compared two model cities with the same two million population, one with a density of approximately 22 dwelling units per hectare and the other with 11 dwelling units per hectare , and found that the average trip distance in the latter is likely to be 20% longer.

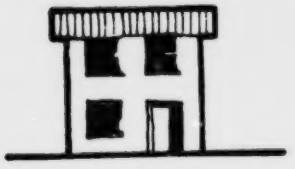
Increased density is also associated with increased transit ridership. This reduces the number of vehicle kilometers and the corresponding energy necessary to provide a given level of transportation service (i.e. passenger kilometers).

Harwood (1977) presents the example of Sioux Falls, South Dakota where, by increasing densities to levels suitable for efficient public transportation, the city could save 90% of the transportation energy required to service more dispersed development. A fairly large population must accompany density in order to justify initial and continuing expenses. Gilbert et al (1973) suggested that energy consumption in the transportation sector is highest on a per capita basis in cities between 5,000 and 25,000 persons and steadily decreases in larger cities, mainly due to increased density and public transit levels.

An American Congressional Report entitled Compact Cities: Energy Saving Strategies for the 80's (1980) found that 60% of the users of Bay Area Rapid Transit (BART) in the San Francisco Area still drive their cars to the train, and 90% of Lindenwald Line commuters in New Jersey go part way by car. Although still a net energy saver, public transit loses many energy-saving characteristics when serving people who live sprawled in all directions.

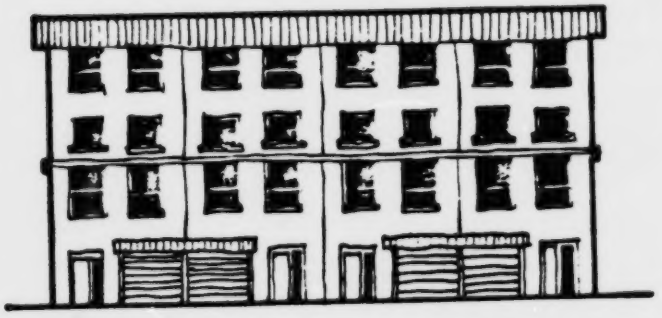
In addition to these advantages increased density achieves higher per capita use of existing road, sewer, water, electrical and other utility networks, thus reducing the initial and continuing costs of expanding these networks. Higher density also results in increased space heating efficiency and facilitates the use of

Figure 9: REDUCTION IN HEATING DEMAND FOR MEDIUM DENSITY AND LOWER DENSITY HOUSING FORMS



100%

Single Family Detached



60%

Multiple Family Residence

NOTE: Heat losses for single apartments are shown as a percent of heat loss of the single family detached house with the same habitable floor area.

district heating. As much as 40% of space heating demand can be saved by encouraging medium density development as opposed to single family residences, according to Griggs (1978). This is due to the greater energy efficiency of higher density building forms (Figure 9).

The term "higher" or "increased density" needs to be defined in order to clarify this discussion. Higher or increased density is used here to refer to an overall medium density. Densities which are too high or low result in the use of more energy both for construction and for operations and maintenance. Apartment blocks require extra energy for elevators, as well as heating or cooling and lighting common areas. What is desirable, is an overall optimum density, achieved by narrowing the range of density within the urban area so that extreme lows in the outer suburbs and extreme highs at the city core are eliminated.

John Hix, (Miloff, 1980) an Ontario architect, proposed a guideline for residential density of 67 dwelling units per hectare implemented through the use of four-storey stacked townhouse structures with self-contained dwellings of two storeys each. Increasing this recommended density, Hix stresses, would result in the use of apartment structures which require more energy, not only to construct but also to operate.

Mixed Land Use

Increasing density is of principal importance when attempting to reduce energy consumption at the city level. Further energy savings accrue by mixing land uses to bring employment, commercial, civic and recreational uses closer to residential areas.

Attempts have been made to find the optimal land use arrangement (Edwards *et al*, 1975; Schofer *et al*, 1977), but most have concentrated on the relative location of residential and employment areas. Clustering of these uses has been proposed as a means of

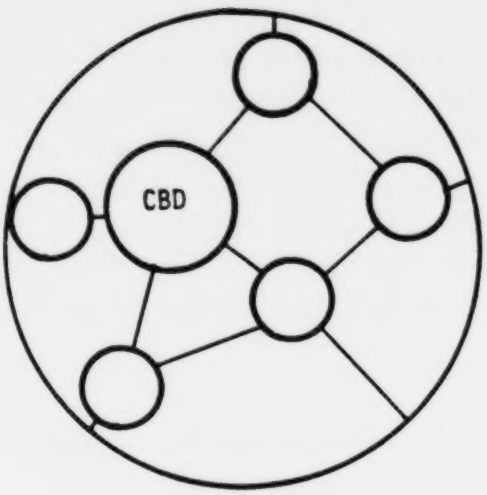
reducing work trip energy consumption (Fels: 1975; Jones, 1974), while Davis, California is encouraging work in the home to reduce the propensity to travel.

In planned communities, particularly where residential and employment land uses are compatible, significant reductions have been indentified in average trip length. Schneide and Beck (1973) for example, indicated that the relocation of only 25% of the population plus 45% of employment would result in a decrease of 40% in travel time plus a 60% decrease in congestion on the busiest road. Although the energy savings of these changes were not analysed, they would appear to be significant.

The mixing of commercial uses with higher density residential areas conserves transportation energy. Portland Oregon, estimated a potential reduction of 1.4% in the total energy used for urban transportation by establishing, neighbourhood grocery stores at 0.8 kilometer intervals. Careful location of schools and decentralization of social and community services will likewise reduce transportation energy usage. The proximities of different land uses would encourage people to walk. Even if this were only partially substituting for other modes of travel, transportation energy consumption would decrease on a per capita basis.

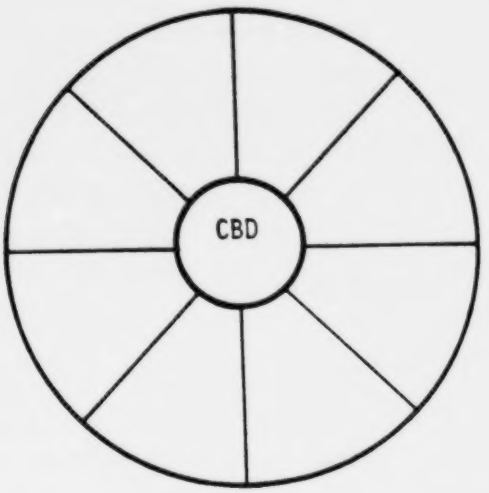
The degree of congestion and average speed of vehicles in the transportation network also affects energy consumption. Automobiles, which consume 65% of transportation energy, are most efficient at speeds of 48 to 72 km/h. Where speeds are substantially below 48 km/h, as in congested inner city traffic, efficiency is reduced and fuel consumption increased. This is attributable not only to the lower speeds, but also to the greater number of idle, stop and start cycles in congested CBD traffic. Cities with several centres of activity (polynucleated) have less traffic congestion than traditional concentric cities, and are therefore, more energy efficient.

Figure 10: CITY FORM AND ENERGY EFFICIENCY



Polynucleated

- efficient mixed use form

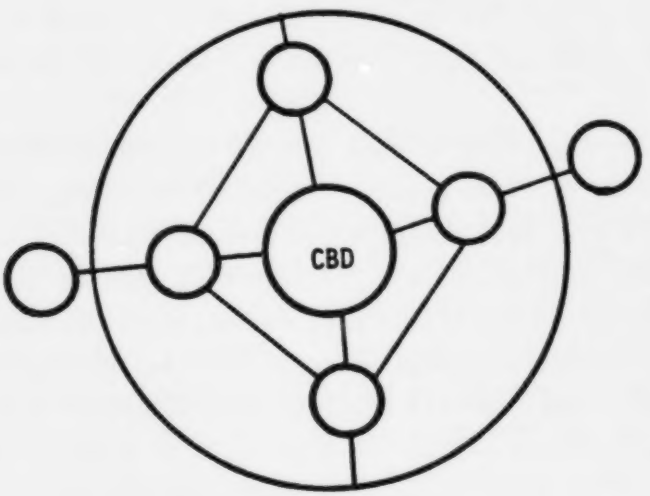


Concentric

- inefficient form

Linear

- efficient transit form



Radial

- combines efficiencies of polynucleated and linear forms

The location of residential, employment and commercial uses affects the role and efficiency of public transit. Higher occupancy levels improve transit energy efficiency, but extremely high or extremely low occupancy levels along portions of a transit route should be avoided. Stringing residential, employment and commercial uses along transit corridors can realize energy savings. The linear city may be the ideal energy conserving form. The ideal city form and land use mix depends on the goals of policy makers: the ideal automobile city may be polynucleated, the ideal transit city, linear. A radial city combines elements of both forms (Figure 10).

Other Principles

Other principles related to city level energy conservation include general constraints mapping and modifying urban systems.

General constraints mapping is a technique determining the most suitable new development areas in a city. The technique involves analysis of existing constraints to development, including geo-technical, topographic, climate, biotic and cultural constraints, in order to determine which areas are suitable and which are unsuitable for different forms of development. Soil survey information is often an important data source for general constraints mapping. General constraints mapping can save energy capital in development and helps prevent development in hazard areas.

Thunder Bay, Ontario used general constraints mapping to compare patterns of urban growth in terms of servicing costs, in order to ensure that development would proceed according to the least expensive alternative. The potential cost savings should be in the order of the millions of dollars saved by communities in Massachussetts through using soil survey information to select school sites, control subdivision development, protect community water supplies and advise developers on sewage disposal systems. Several of these communities indicated savings in the order of 110 to 1 effected by avoiding errors in the use of land. This represents large savings in embodied energy or energy capital.

Modifying urban systems can save energy in development and in city operations. Urban systems include roads, utilities, public transit, garbage disposal and other municipal operations. Street lighting is one example of the energy savings possible through modifying urban systems.

Mississauga, Ontario initiated a program in 1978 to convert all street lighting in that city to a high pressure sodium system. The total conversion cost of approximately $160,000 will be amortized in eight years. A reduction in electrical consumption of 700,000 kwh annually due to the more-efficient lighting saves an estimated $40,000 per year.

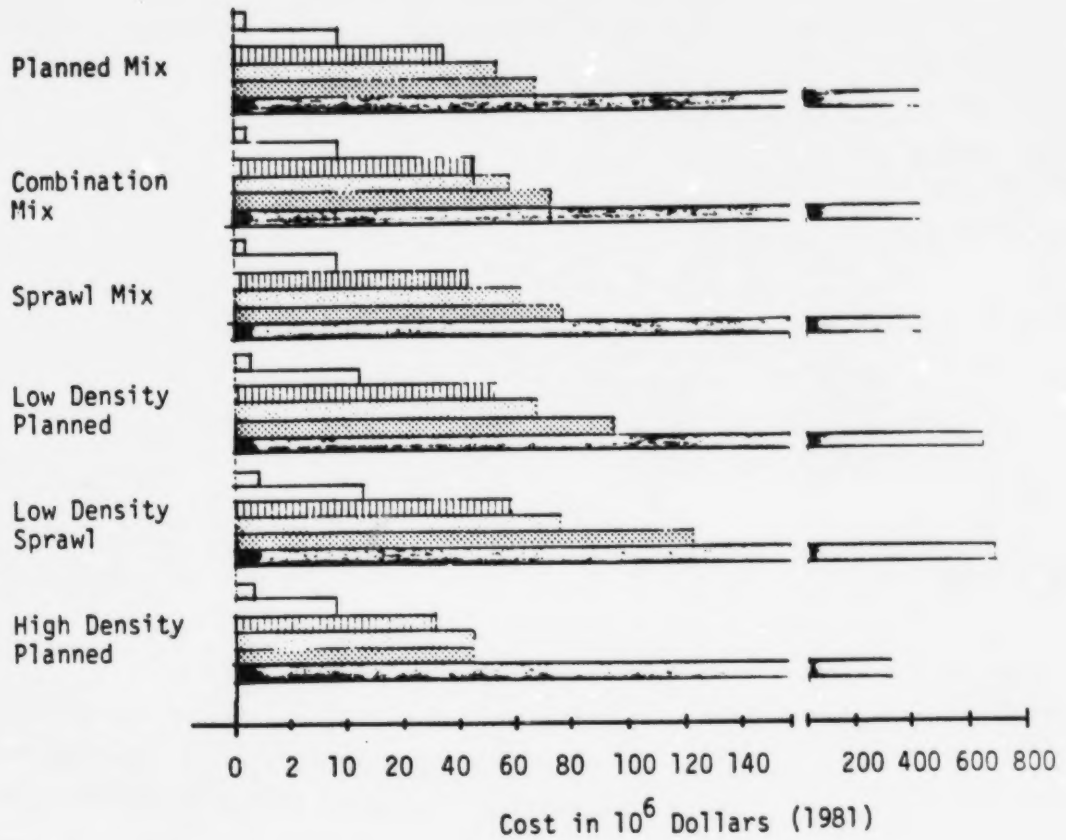
4. IMPLEMENTATION STRATEGIES

New Development Areas

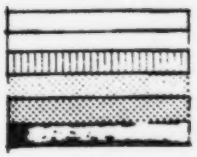
Increasing density and mixing land uses can reduce the energy requirement for transportation between 5% and 40%. The application of these conservation approaches to future expansion areas is accomplished through careful planning by both the public and private sectors.

The vagaries of urban land holdings often lead to development not contiguous with existing built-up areas. Such leapfrogging creates large gaps (no-man's-lands), between developed areas and, like low-density sprawl, is responsible for high energy consumption. Leapfrogging results in increased travel distances, makes alternative forms of transportation unjustifiably expensive and necessitates lengthy and costly extensions of existing road and utility networks. In addition, prime cropland near metropolitan areas is lost to sprawl. For every hectare taken for urban uses, an additional hectare is idled or isolated by non-contiguous development. This reduces the efficiency of agriculture by increasing the energy required to produce crops on lower quality land and to move agricultural goods to market.

Figure 11: COMMUNITY DIRECT COST ANALYSIS
10,000 units


Planned Mix
Combination Mix
Sprawl Mix
Low Density Planned
Low Density Sprawl
High Density Planned
0 2 10 20 40 60 80 100 120 140 200 400 600 800
Cost in 10^6 Dollars (1981)

LEGEND:



Streets & Roads (operation & maintenance)
Utilities (operation & maintenance)
Land (capital-developed & vacant improved)
Streets & Roads (capital)
Utilities (capital)
Residential

	Single-Family Conventional	Single-Family Clustered	Townhouse Clustered	Walk-up Apartments	High-Rise Apartments
Planned Mix	20%	20%	20%	20%	20
Combination Mix (50% PUD, 50% Sprawl)	20%	20%	20%	20%	20
Sprawl Mix	20%	20%	20%	20%	20
Low Density Planned	25%	75%			
Low Density Sprawl	75%	25%			
High Density Planned		10%	20%	30%	40

Source: Real Estate Research Corp., 1974

The "Community Direct Cost Analysis" Chart (Figure 11) illustrates the costs which could be incurred by a community as a result of different types of development. For purposes of clarification, "low density sprawl" and "high density planned" are at opposite ends of the spectrum. Of particular significance are the capital costs indicated for utilities and road construction associated with low density sprawl. A community could save as much as 32% and 40% on the provision of utilities and roads, respectively, if development was high density planned as opposed to low density sprawl. According to The Costs of Sprawl (1974), higher density planned communities use 44% less energy than unplanned, sprawling communities. Other research (Altshuler, 1979) suggests this figure should be closer to 14%. A range from 15% to 20% would be credible on the basis of recent research.

Existing Development Areas

Although energy conserving principles are more easily applied to new development areas, approximately 70% of the urban infrastructure required by the year 2000 in Canada already exists. Existing developed areas, simply by their magnitude, have the greatest potential for energy savings. They are, at the same time, more difficult to alter. Restructuring existing parts of the urban area may entail higher capital costs and energy use than developing new areas. Altering the existing fabric may require insitutional changes in planning, architectural and engineering practices. The benefits of altering the existing city fabric are in reduced costs per capita for the provision of road and utility networks, as well as reduced transportation expenditures. Since these networks are already in-place the millions of dollars associated with providing them in new areas can be eliminated. Similarly operating and maintenance costs can be substantially reduced. However, these may benefits may be partially offset by soaring land prices.

Altering existing developed areas implies redevelopment, rehabilitation and conversion or infill development, or any combination of these strategies depending on the structure and quality of each area.

Redevelopment

Redevelopment of existing areas facilitates replacement of older, less energy-efficient environments with energy conserving forms. Redevelopment typically occurs in older core areas where large expenditures are required for upgrading.

The Winnipeg Core Area Initiative demonstrates the type of incentives required in most instances to upgrade decaying core areas. The program, funded by the three main levels of government, attempts to identify and implement programs and projects which will improve the social, economic and physical components of the core making it both attractive and usable.

The decision to redevelop an older areas is not likely to be made on the basis of energy conservation alone but, while redevelopment is normally associated with high initial costs, long-term energy costs can be reduced. When redeveloping existing areas the potential exists to implement high density planned unit developments (PUDs) or mixed use complexes. PUDs increase residential densities and sometimes mix land uses, while mixed use complexes often combine a wide range of business, commercial, entertainment and residential uses, resulting in predominantly self-contained areas where travel distance may be markedly reduced.

Providing one kilometer of roads, water and sewer lines in a typical sprawling suburb of single-family homes costs about $312,000 (1980), assuming a density of 7.9 dwelling units per hectare. In a typical city, due to obstructions and higher land costs, the same kilometer of new facilities, would cost about $406,250: 23% more. Obviously, savings are not related to the

original construction, nor are they related to operations and maintenance costs, which are about the same. Savings arise because of population density. The per capita cost of providing the facilities in the low-density suburb is $5,000, but in the city, only $540: 89% less.

Planned unit developments and mixed use complexes already exist in many Canadian cities. Although not built with energy conservation in mind, these developments and complexes have produced spin-off savings in transportation related to residential land use by reducing distances travelled to services. Calgary's Eau Claire represents a downtown redevelopment which is characteristic of planned unit developments and incorporates higher densities (apartments and row-housing) with a mix of land use types. Similarly, the Bay Complex in Toronto attempts to rejuvenate the downtown core by providing a mix of residential, commercial and office facilities within a megastructure that occupies an entire city block. In both examples public transit facilities are integral parts of the developments.

False Creek and Granville Island are illustrations of how to turn an urban eyesore into an attractive environment close to the heart of Vancouver. False Creek is a medium density residential redevelopment closely linked to work, shopping and recreational opportunities in the converted and revived industrial area on Granville Island. False Creek and Granville Island are heavily reliant on public transit.

Rehabilitation and Conversion

Rehabilitation of older neighbourhoods provides an opportunity to revitalize areas characterized by high vacancy rates and out-migration. There are many examples of rehabilitation and conversion in Canadian cities which, while initiated for reasons other than energy conservation, serve to increase density and mix land uses.

Toronto's Cabbage Town has progressed rapidly from an area of run-down tenaments to a highly desirable neighbourhood with easy access to the city core. What started as cautious rehabilitation of 19th century row-housing purchased at low prices, has escalated to the point where living in one of these renovated units has become fashionable and expensive.

Conversion of existing neighbourhoods also increases density and provides for a mix of land use types. Large older homes in many Canadian centers have been upgraded and converted to multi-family dwellings. Similarly older homes in certain areas have been converted to incorporate multiple uses - commercial on the first floor level and residential on the upper floors. Sometimes inner city initiatives are fortuitous, sometimes planned. Toronto experienced a wave of downtown rehabiliation and conversion after passing a by-law restricting building heights in the downtown area. The Yorkville area of Toronto is a prime example of a rejuvenated older residential area which incorporates a mix of land use types. Rehabilitation and conversion often provide the stimulus for infill developments.

Infill

Infill development can result in significant energy savings within existing developed areas. Most cities have large areas of vacant or underutilized lands. Peter Barnard estimated in his study of Infill Housing in Winnipeg (1980) that Winnipeg has enough land available for infill development to accommodate growth for the next twenty years. If this land is properly developed, more efficient use will be made of the existing infrastructure.

Within most Canadian cities there are obvious benefits to infilling vacant or underutilized lands, particularly from the standpoint of reducing transportation energy consumption associated with residential land use. Barnard found annual personal trans-

portation costs within the city, were approximately 51% less expensive for families living downtown as opposed to the suburbs. A four person family in the city, with one car, incurred annual transportation costs of $2460 (1981 prices), while a similar family in the suburbs, with two cars, incurred annual costs of $5120. The viability of sensitive infill development is dependent on a complex set of circumstances which differ from location to location. These include market demand, development economics, municipal policy and the support of concerned parties.

Small-scale infill is primarily intended to help maintain and reinforce existing healthy neighbourhoods but can be a catalyst for some neighbourhood revitalization. Infill, alone, is not of sufficient scale to have a major impact in large areas of decline. In such areas infill should be part of a major revitalization effort, involving improvement of public services and facilities, assisted rehabilitation and new housing.

Planning Strategies

Different urban centers have tackled legislation to stimulate the development of energy conserving urban form in various ways. Restructuring existing urban form to increase density and mix land uses requires special policy and design strategies, often changing accepted standards. Legislation to encourage such restructuring must therefore be flexible as well as readily accepted and easily implemented.

Energy management and changes in development plans, secondary plans, zoning by-laws and development agreements may conserve energy in the following ways:

- changing conventional housing type and density requirements to broad general categories will permit different house forms and innovative development or redevelopment;

- incorporating different land uses, increases residential proximity to commercial social and recreational facilities and more efficient use of public transportation facilities;
- using environmental constraints mapping as a general guide to development will ensure that land uses are situated in areas with few development constraints and the least environmental hazard, and
- modifying urban systems will increase efficiency.

The following examples indicate how certain jurisdictions have implemented comprehensive policies for energy management and conservation.

San Diego County, California

The San Diego County General plan is composed of several 'elements', of which the "Energy Element" is a major policy statement regarding the County's role in energy resource planning.

The major topics in the "Energy Element" of the Plan are presented as scenarios which address energy demand and supply, the impacts of various conservation tactics, the rationale for selecting a reduced energy growth rate, and the policies and implementation strategies required to reduce energy growth rates to desirable levels.

Emphasis has been placed on implementing strategies which have been found to have substantial savings, either independently or in combination with others.

Of particular significance are policies which attempt to reduce the energy consumption associated with transportation, general land use arrangements and housing through the restriction or modification of undesirable development. These include encouraging increased development densities through emphasis on attached residential units in new areas and infilling in existing areas,

and promoting land use aimed at minimizing transportation requirements, such as a greater mix of residential and commercial, or equally compatible, land uses. Other policies promote mass transit and bus service, and safe and practical walking and bicycle routes within the County. The plan recognizes that the transportation sector is a major user of energy and that choices between developed modes of transportation will be the prime determinants of future energy needs. Attempts have thus been made to promote interconnections between these planning decisions related to land use and those related to transportation. Attempts have also been made to incorporate performance parameters for the year 2000 indicating each policy's effectiveness relative to the others.

Portland, Oregon

The City of Portland, (population 365,000) has taken a legal and regulatory approach to conservation by developing a comprehensive energy plan which relies heavily on the city's power to shape growth and mandate conservation. After 1984 homeowners will have to meet mandatory weatherization requirements such as installing storm windows and insulation. Weatherization loans are available through a HUD Action Grant matched by local lenders. Cost-effective standards require that the cost of weatherization and new fuel bills be less than or equal to previous fuel bills. Rental and business properties face similar stiff requirements. The plan also has a land use component encouraging compact growth and integration of new development with mass transit systems.

Portland, Oregon was one of the first cities to attempt to quantify potential energy savings related to the application of particular land use strategies (Table 2). The main objective of the Portland Energy Conservation Management Demonstration Project was to develop a methodology that could be used to predict potential energy savings from changes in the urban form. The savings of over 85 conservation programs were calculated and 42 were used in assembling a comprehensive energy plan.

The methodology used to calculate energy savings was designed to be applicable to other U.S. cities, although the savings would differ with climate and building code, and has potential for application in Canada.

Portland is also considering use of "energy zones". Priority would be given to capital improvements and development proposals located in zones well served by public transit, utilities and services, andn located near the CBD and close to employment and shopping.

Seattle, Washington

In 1976, the City of Seattle (population 500,000) passed five resolutions which together comprise a comprehensive municipal energy policy. The resolutions involve the following:

- developing new energy efficiency building codes aimed at improving construction and increasing densities;
- forecasting electrical energy demand to project baseline levels of electrical demands;
- specifying energy conservation policies in the city's comprehensive policy plan;
- governing power generation by resource use, energy conservation, sound economics and environmental responsibility, and;
- preparing a contingency planning program for energy use.

The plan seeks to use land in downtown Seattle more coherently: intermixing living and working space in a denser pattern, and reducing energy consumed in commuting. Free bus service for the downtown is intended to cut down on automobile use. Residents seeking to switch to electricity must install insulation and other energy-saving features. The city is also investigating other energy sources including coal-fired generating plants, biomass, solar and wind energy.

TABLE 2

TRANSPORTATION AND LAND USE CONSERVATION CHOICES, CITY OF PORTLAND, OREGON

Implementation Program	Maximum 1995 Energy Savings Billions (10^9) KJ Per Year	Maximum & Savings of Regional 1995 Projected Demand	
		Transportation	Residential
RESIDENTIAL LAND USE AND TRANSPORTATION			
Townhouses and apartments along transit street	11,621.5	6.0	7.6
Townhouses and apartments near employment centres	8,840.3	5.4	5.7
Townhouses and apartments near shopping centres	9,935.5	5.3	6.7
Townhouse and apartments near transit stations	9,937.6	6.2	6.2
Zoning change to allow apartments in large homes	1,040.3	1.2	1.3
"Infill" housing on vacant single parcels	270.1	0.2	N.E.
Require two-storey construction in dwellings greater than 1,100 sq. ft. (handicapped persons excepted)	929.5	N.E.	0.4
COMMERCIAL/INDUSTRIAL LAND USE AND TRANSPORTATION			
Neighbourhood grocery stores	1,269.2	1.4	---
Limited expansion of strip retail development	174.1	0.2	---
Allow home occupations (office type)	153.0	0.1	N.E.
Reuse of waste heat	1,831.6	---	2.5
PUBLIC LAND USE AND TRANSPORTATION			
Build exclusive bicycle paths	287.0	0.3	---
Lower speed limits to 45 mph	366.1	0.4	---
Improve traffic flow	418.8	0.4	---
Car/van pool incentives	3,589.1	6.1	---

Source: Policy Analysis Section Bureau of Planning, City of Portland, Oregon (1977).

Toronto, Ontario

As a result of concern over rising energy costs, Toronto City Council passed a by-law to amend the Official Plan and include statements on energy efficiency. Toronto, a city of 610,000, within a census metropolitan area of nearly 3 million, is a built-up inner city with a vital core area, a mixture of high-density residential complexes and mature, low-density residential neighbourhoods and a multi-modal transit system.

The goals of the by-law are to minimize energy use while improving urban quality of life, to replace non-renewable resources, particularly oil, with renewable energy sources, and to minimize inequities caused by higher energy prices and possible shortages.

Policies pertain to energy conservation, urban form and public involvement, and are guided by the principle that all measures should be cost-effective. The policies include encouraging development or redevelopment contributing to energy-efficient urban form, including appropriate densities and mixed land use, and encouraging reduction in the consumption of non-renewable fuels for transportation.

The City has completed a Municipal Energy Audit and is exploring such measures as cogeneration of electricity and steam for district heating, conversion of sewage for district heating and developing guidelines for assuring solar access in medium and high density developments. In addition a community retrofit demonstration program has been started.

Winnipeg, Manitoba

Awareness of the energy saving-benefits of restructuring the city toward a more compact, and integrated form is growing. Plan Winnipeg 1981, while nowhere specifically mentioning energy, consistently emphasizes policies to strengthen Winnipeg's developed

areas through infilling, while limiting development beyond the existing built-up area. The Plan sets the tone of political and administrative action in the city (population 600,000). Developers proposing expansion subdivisions are being required to provide full assessment of the capital impacts of their developments.

Slow-growing cities, like Winnipeg, and cities with major geographic constraints to expansion, like Vancouver, have begun to focus inward; and even fast-growing urban centers without major impediments to expansion, such as Calgary, have instituted policies to increase urban densities and stimulate infill. In urban regions such as Toronto, certain policies as well as the economics of size, have been shown to have the effect of stimulating downtown migration and redevelopment.

Davis, California

The City of Davis, California (population 36,000) is attempting to reduce energy consumption with respect to work-related travel, by encouraging people to live and work in the same neighbourhood. A number of different ordinances have been passed to achieve this objective. One, for example, requires the purchaser of a residence to also reside on the property. This is achieved by requiring the buyer to sign a declaration that he will move into the house within six months of the purchase date and reside there for a period of at least a year. Although loosely implemented, the ordinance has been found to be effective in stimulating people to live in close proximity to their place of employment. Another encourages cottage industry by allowing home owners to operate small businesses.

The Davis General Plan encourages a wide variety of conservation measures including: shading, drought-resistant vegetation, alternative transportation modes (bicycles and transit), recycling of non-renewable material, conservation of prime agricultural land, energy conservation standards for buildings and priorities in new development and renovation. The City enforces these planning policies through ordinances and development reviews.

Between 1973 and 1978 electrical consumption in Davis dropped 10.1% and natural gas consumption dropped 25.9%. Comparison indicated that other areas in the general vicinity experienced increased consumption of electricity and a much slower delcine in natural gas consumption. However, some declines in energy use were found to have occurred in Davis prior to implementation of the General Plan, distorting estimates of energy savings resulting from these policies.

Montgomery County, Maryland

Unlike the examples just quoted, planners, developers and politicians in Montgomery County, Maryland are encouraging mixed land use in their community, and higher density in relation to public transit routes, through a zoning by-law. The county, by permitting the mixture of some uses and allowing others on special permits, is maximizing public transit uses, bicycling and walking, while minimizing reliance on the automobile. Montgomery County has a variety of mixed use zones. The TS-R zone, for example, is designed to combine several types of residential uses with institutional and local commercial uses. Hotels, restaurants, grocery stores and drugstores are allowed by special permit. The zone is flexible in the design, layout and grouping of uses to facilitate the successful integration of different land uses in a residential transit zone.

Boulder, Colorado

The City of Boulder (population 80,000) encourages the location of new development close to a variety of existing facilities and services by granting bonus points for such practice to developers, who must compete for a limited number of development permits annually. The maximum number of points is awarded for the following distance parameters:

- the project is within 1.2 km of a developed neighbourhood park;
- half the project is within 0.4 km of existing bus service;
- the project is within 1.6 km of three of the following facilities: library, recreational centre, day care centre, neighbourhood shopping facilities with at least a grocery store;
- the project is within four minutes of fire department response;
- the project is within safe walking distance of two of the three schools that serve it (distance unspecified).

Windsor, Connecticut

The Town of Windsor offers density bonuses to encourage conversion of one and two family residential structures to office and multi-family use if the projects are near convenience shopping and mass transit. Other requirements and incentives set forth in the town's zoning regulations include:

- for planned unit developments: all residential units must be within 2.4 kilometers of one elementary school and within 1.6 kilometers walking distance of an existing bus route;
- for developments in the CBD: if the location of the development generates sufficient pedestrian, bicycle and mass transit trips, required parking may be reduced up to 10%, subject to the discretion of the Planning Commission.

Windsor also reduced subdivision code standards for the width of culs-de-sac and one-way-loop local streets. When parking is restricted to one side of the street culs-de-sac may be 7.3 meters wide and one-way-loop local streets 6.1 meters wide. The previous standard for both was 9.1 meters wide.

Brampton, Ontario

Brampton (population 140,000) was the first city in Canada to require the application of passive solar design principles to all

new subdivision plans. The Brampton By-Law was based on eight energy conservation criteria proposed by the city's senior planner including: siting and designing buildings for solar orientation and solar access; designing for pedestrian movement and use of public transit, and developing mixed use centers. The criteria also formed the basis of the city's Energy Policies concerned with the following:

- promoting greater local self-reliance;
- reducing consumption of non-renewable energy sources;
- siting buildings for proper sun and wind orientation;
- protecting solar access;
- encouraging mixed use developments and a comprehensive waste recycling programme, and
- promoting public transit.

In 1979 the Brampton City Council approved the formation of an Energy Conservation Committee to inventory energy use by city-owned or operated facilities, to prescribe conservation measures, to monitor future energy use by city-owned or operated facilities and to involve the general public in a programme of public relations and information dissemination. Public understanding and involvement are deemed essential if passive solar and other design measures being applied to the city's subdivisions are to achieve their potential energy savings.

5. MUNICIPAL TECHNIQUES

Intentionally or not, municipalities affect large changes in energy consumption patterns through their policy decisions. Many changes in urban form, while the result of economic lobbying, social planning decisions or other factors, also have an impact on energy conservation. In many Canadian cities, economic and lifestyle factors have led to the development of PUDs and higher density zero-lot-line housing forms, which increase density and

save energy. Social factors have stimulated inner-city revitalization through conversion of older houses and obsolete land uses, mixing land uses and infilling. In the long run, such actions save energy in urban transportation and infrastructure.

The implementation examples in this chapter indicated possible techniques for achieving conservation objectives:

- energy management teams help keep energy expenditures low;
- development plans and policy statements provide a general framework for conservation actions;
- by-laws, codes and other development controls regulate conservation actions, and
- the development approval process encourages the understanding and application of energy conservation techniques in new developments.

Energy management teams provide expertise to advise municipalities on energy problems, conservation strategies and implementation techniques. They also manage and monitor conservation actions.

Municipal development plans influence community goals, the kind of development allowed in different areas and the timing and capacity of municipal infrastructure. They have a significant effect on overall urban form. An energy policy statement may be developed as part of a development plan, or as a separate document. Energy policies either direct actions dealing with problems over which a municipality has total or substantial control, or advocate actions dealing with problems over which a municipality has little or no control.

By-laws, building codes and other development controls are specific regulations which provide the means for implementing energy conservation strategies. Coupled with a development approval process which encourages the understanding and application of

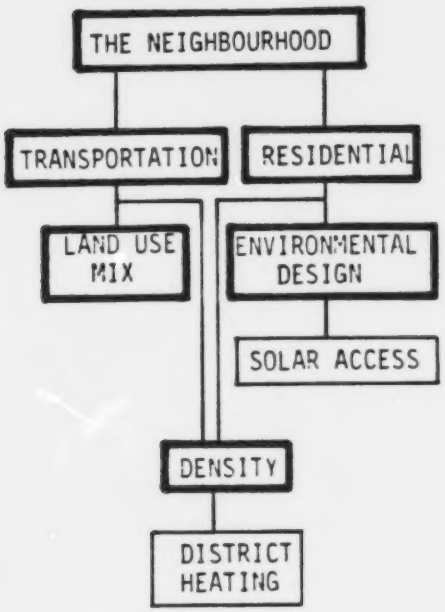
energy conservation techniques, such regulations will ensure that energy-saving measures are built into new urban environments. The approval process may serve, as well, as a means of educating developers in energy conservation and encouraging innovative energy-saving plans.

The extent to which any of these implementation techniques fit a particular city depends on the local energy situation, public awareness of energy issues, the concern of local government and unique local factors of geography, history and government. The energy crunch in the Pacific Northwest of the United States focussed public awareness and local government concern, and led to the formulation of tough, comprehensive energy policies and development controls. Similarly, energy legislation in San Diego County and Davis, California was the result of the threat of real energy shortages. In areas which are secure in short-term energy supplies, the move toward energy-conserving form is more the result of economic arguments. Winnipeg and Calgary would like to limit peripheral development and encourage infilling in order to minimize future capital costs.

CHAPTER 4

THE NEIGHBOURHOOD

Figure 12: THE NEIGHBORHOOD LEVEL



1. NEIGHBOURHOOD LEVEL APPROACHES

Neighbourhood energy conservation focusses on four main approaches including:

- compact form and mixed land use;
- district heating;
- environmental design, and
- solar access.

These approaches (Figure 12) are sets of design principles. Neighbourhood energy conservation requires tradeoffs between approaches and principles which are not compatible. In order to demonstrate the energy saving potential of different approaches and principles, as well as to indicate where tradeoffs occur, the chapter is organized in terms of general costs and benefits, energy conservation principles, examples and conclusions.

Both embodied energy and operational energy are saved through the application of neighbourhood energy conservation principles. Embodied energy is the amount of energy expended to manufacture and put building and infrastructure materials (and systems) in place; operational energy is the amount of energy expended in the day-to-day functioning of a neighbourhood, including: space conditioning, (heating or cooling buildings) heating water, running appliances, operating vehicles and maintaining infrastructure. Compact form and mixed land use, and environmental design approaches save both embodied and operational energy; district heating and solar access approaches save operational energy. District heating and solar access are space heating approaches whose effectiveness must be measured against the viability of other energy transmission and exchange systems. District heating is related to compact form and mixed land use, solar access to environmental design. Compact form and mixed land use and environmental design principles have a more general applicability and a greater potential for overall energy savings than district heating and solar access.

The magnitude of the potential energy savings for any approach or combination of approaches varies between individual development sites, as well as between energy zones.

An important consideration in determining energy savings related to a particular energy saving approach is the thermal efficiency of housing units. As the thermal efficiency of the building envelope improves, the marginal energy contribution of energy conservation measures such as district heating, wind protection and solar access, becomes less important, and their ratio of costs to benefits shifts to an undesirable level. Careful consideration of low-energy residential design costs and benefits should be a first step in neighbourhood design for energy conservation.

Ultimately, the decision to apply certain conservation measures may be based on concerns other than energy economics. Marketability, cost-benefit accrual, development regulations and technical know-how may severely limit the application of energy conservation principles in a development.

The concerns in initiating energy conservation at the neighbourhood scale are as follows:

Marketability

Consumer reluctance to accept innovative options and builder resistance to including such options, is a major concern in incorporating conservation approaches. Uncertainty about exact energy savings, coupled with the lack of performance guarantees, are the two largest obstacles to selling energy efficient plans. If these are overcome innovative options would enhance the marketability of a development.

Cost/Benefit Accrual

Developers are concerned about the disparity between who pays for and who benefits from energy-efficient plans. While the risks and costs accrue to the developer and builder, the benefits generally accrue to the consumer, public utility and public at large.

Development Regulations

Local development restrictions can present unintentional barriers to the application of energy conservation approaches. Even energy conservation by-laws can hinder the application of worthwhile principles. Solar access bylaws which require all streets to be oriented east-west may ignore the energy conserving benefits of designing with existing topography while ensuring solar access through performance standards for window orientation.

Technical Know-How

Athough a general list of planning principles is emerging, a specialized team is often required to identify, screen and evaluate the means of increasing energy efficiency at the neighbourhood scale.

Governments will have to counter all these concerns if they believe energy conservation to be worthwhile, especially if energy savings have a net dollar cost to consumers. This can be done through demonstration projects, monetary grants and revised planning regulations. Neighbourhood conservation measures are essential to savings at other levels. For example, as the size and density of a neighbourhood increases, so does the viability of a public transit system, which is a city-level concern. The layout of neighbourhood streets and lots also affects the ability of housing to use solar energy or to channel winds, which is a residence-level concern.

The intention of this chapter is to outline "how-to" methods for energy conserving design. At the end of the chapter is a comprehensive checklist which can be used to review the energy conserving potential in a given residential development proposal.

2. COMPACT FORM AND MIXED LAND USE

Compact form and mixed land use save both embodied energy and operational energy in neighbourhoods. Energy will be saved in three main ways, including:

- reducing the space conditioning (heating and cooling) requirements of residential buildings;
- reducing transportation requirements within the development, and
- reducing the infrastructure (roads and utilities) required in the development.

The magnitude of savings will vary on a project-by-project basis; however, a rough estimate based on the findings of a number of studies would suggest that compact form and mixed land use will save 10% to 40% of space conditioning requirements; 5% to 15% of transportation requirements and 10% to 20% of infrastructure requirements. Reducing road and utility requirements will also reduce operating and maintenance energy use.

Principles

Energy-conserving neighbourhood form involves three parameters: density, land use mix and urban systems.

The first neighbourhood form parameter involves increasing density. Increasing the density (compactness) of a development from single-family detached housing at about 12 du/ha to multiple housing at 67 du/ha, will reduce heating requirements 40% due to a reduction in exposed surface walls. (The higher density is equivalent to

stacked townhousing.) The Costs of Sprawl (1974) indicates that a 33% cost saving (representing a saving in embodied energy) can be achieved through developing neighbourhoods with a 20% mix of multiple family housing rather than homogeneous single-family detached housing. Greater compactness will also increase the viability of district heating systems and public transit use.

The second neighbourhood form parameter involves mixing land use. This, in conjunction with more compact form, will reduce transportation requirements (See Chapter 3). Mixing land use can be achieved through developing multi-use structures; zoning to permit a flexible distribution of land uses - including residential, commercial, institutional and recreational uses, and encouraging work at home.

Reduced distances between housing units will reduce road and utility lengths required to service the neighbourhood, in addition to maintenance. The Costs of Sprawl (Real Estate Research Corportation, 1974) suggests that utility costs, an indication of embodied energy, could be reduced 15%; while operating and maintenance costs could be reduced 5% to 6% between planned high density and low density sprawl development. (Detailed figures indicating neighbourhood savings in embodied and operational energy are found in Section 4 of this Chapter, page 67.)

The third parameter is improving the efficiency of neighbourhood infrastructure. This includes roads and utilities such as storm and sanitary sewers, water mains and electrical lines. Planning which reduces the number of local streets and ensures an efficient street hierarchy will also conserve energy. The use of culs-de-sac, while desirable for other reasons, requires extra maneuvers on the part of snow-clearing equipment, restricts snow storage and costs more to service than through streets.

These three parameters require a thorough evaluation of the overall neighbourhood development concept, internal zoning and layout of streets and utilities. Full implementation of compact form and mixed land use principles will be dependent on marketing perceptions and development regulations.

Locational factors are another important consideration in designing for energy conservation. A project remote from existing services and facilities may require excessive energy for the construction of roads and utilities, for transportation and for utility line losses. Where development options are limited, developing a self-contained neighbourhood, incorporating all necessary services and facilities, or providing mass transit will reduce energy demand.

Low-density development creates a dependence on the automobile for transportation, along with inefficient street and lot layouts. Increasing density through clustering single-family detached lots, using zero-lot-line regulations or developing higher density planned unit developments (PUDs) will improve transportation and utility energy use.

PUDs are higher density neighbourhoods with integrated designs for streets, utilities, buildings and landscaping. Depending on the scale of development a PUD can incorporate a wide mix of land uses and can modify density, road width and other, often rigid, zoning and development regulations. A PUD may save as much as 45% of the energy used in sprawl. Neighbourhood PUDs can use cluster development and high density housing forms.

Reductions in street and utility lengths and creation of a traffic hierarchy with a favorable traffic flow (reducing stops and starts) will reduce inefficient automobile use, and reduce the capital costs of street and utility construction.

Street widths can be reduced in many cases without impairing this ease of movement, again saving in capital costs, and also reducing heat buildup due to large areas of asphalt.

Developing bicycle paths and walkways through a neighbourhood will further decrease dependence on motorized transport and save energy. Higher density and mixed land use fit this.

Detailed systems alterations, aside from reducing road widths, include selecting energy-efficient building systems and materials to avoid energy intensive construction; wood or masonry walk-up apartments being more efficient than elevator high-rises. Street lighting is another example: maintaining reduced street lighting standards, where consistent with public safety, and using high efficiency low-pressure sodium fixtures, will save in the construction and operation of street lights.

Examples

St. Lawrence Neighbourhood, Toronto, Ontario

The St. Lawrence Neighbourhood in Toronto, is a large inner-city redevelopment venture involving the re-zoning of 18 ha of marginal industrial land to allow creation of a residential and commercial mixed use area for a projected 10,000 people.

The overall plan shows townhouses clustered around interior loop roads, buffered from adjacent traffic arteries by higher density apartments containing street-level retail arcades.

Based on the philosophy "you can't impose a suburban approach on an inner-city development", densities are as high as 136 du/ha. The PUD stretches 1.6 km across 11 city blocks and is cut off from Toronto's residential fabric and bounded by a railway line and the Gardiner Expressway.

The developer has tried to recreate the fabric of the original neighbourhood through designing buildings to fit the style and layout of existing city streets, keeping apartment blocks long and low, and running the full length of a block. Exterior walls are clad in brick, commonly used in Toronto developments.

Additional engineering costs were required in the development of this inner city area to seal off industrial wastes such as oil, grease and methane gas.

The St. Lawrence Neighbourhood projects an energy budget of 194 kwh per square meter per year for the attached housing. This is an 18% improvement in energy use over other projects with a similar mix of apartments and townhouses and with average consumptions of 237 kwh per square meter per year. Heating systems are hydronic to allow for conversion to district heating using a gas-fired central boiler, or innovative sources including steam from a nearby waste incineration plant, or hot water from heat pumps using the nearby interceptor trunk sewer.

Although other energy benefits have not been accurately measured, the high density and mixed use development will save local and regional transportation energy. Proximity to downtown Toronto, along with good transit opportunities provide the opportunity for high levels of transit ridership.

Solar West, Vancouver, British Columbia

Vancouver's Solar West development, a 50 ha tract of City-owned land, employs four major principles of energy conservation:

- consolidation (increasing densities);
- integration (mixing land uses);
- location (responding to slopes, aspect and contours), and
- orientation (responding to the path of the sun).

Net densities in Phase 1 of Solar West are the equivalent of townhousing (37 du/ha) although most of the residences are semi-detached or joined only by common garages. Smaller, narrower lots allow for intensified land uses.

Recognizing that the transportation system is the largest single user of energy within a neighbourhood but that many measures for reducing transportation energy consumption require changes in public attitudes, the site plan incorporates measures such as:

- developing pedestrian and bicycle paths;
- reducing road lengths and widths, and
- increasing access to public transit.

Similarly, the energy used in utilities, materials, construction and maintenance is reduced through:

- reducing utility lengths by ensuring the development is contiguous with already serviced areas and building at higher density, and
- reducing service component size by combining smaller lots and short roads off collector streets on which main utility lines run.

Burke Center, Virginia

Burke Center, Virgina; one of five developments studied by SAND, the Site and Neighbourhood Developent Program (1981) in the United States, employs a number of principles related to compact form and mixed land use. Higher density is achieved through the use of four-plexes and clustering, which reduces requirements for roads and services. Road patterns were adjusted to reduce trip lengths and development standards were modified to minimize street widths and parking requirements. In addition, a park-and-ride system was incorporated to reduce energy use in trips to work and shopping. Burke Centre employs an efficient solid waste collection system which requires 41% less energy than a conventional system.

All this was done with an understanding of market conditions. The principal cost and energy savings for Burke Center relate to infrastructure savings, and these are presented in Section 4 of this chapter.

Radisson, New York

Radisson, New York, another SAND project, developed an efficient electrical distribution network which reduced line losses more than 50% compared to conventional servicing: $19.60 per residence as opposed to $40.00 per residence.

Davis, California

In Davis, California, new street widths are determined primarily on the basis of the width of fire trucks. The resulting narrower streets use less asphalt and cost less to construct. Savings in land and site development could be as high as $1000 per lot. Davis reduced local street right-of-ways from 10.4 to 8.5 meters with the possibility of further reduction in conjunction with neighbourhood parking bays.

Davis has also encouraged bicycle and public transit use and developed legislation to encourage work at home.

Conclusions

Compact form and mixed land use principles are applicable to all developments. The extent to which principles are applied will depend on the developer's objectives, market factors and development regulations. The following principles have demonstrated energy savings.

1. Densities between 67 du/ha and 94 du/ha will produce energy savings. Between 30% and 40% of the energy used to heat single-family detached housing units could be saved by developing at these higher densities.

2. Higher density and mixed land use will produce transportation energy savings in the order of 8% to 14%.

3. Higher density will produce savings in utility costs, and operational and maintenance costs in the order of 15% and 5% to 6%, respectively.

4. Excessive energy consumption for offsite transportation, infrastructure construction and transmission line losses can be reduced by developing self-contained, mixed use neighbourhoods or mass transit.

5. Embodied and operational energy for streets and utilities may be reduced by increasing density. This could be done by developing PUDs, cluster housing or zero-lot-line housing.

6. Embodied and operational energy for streets and utilities may be reduced by efficient and innovative road and utility planning. This includes ensuring an efficient street hierarchy, reducing street widths and minimizing utility lengths by using special utility corridors.

3. DISTRICT HEATING

The viability of district heating increases with increased density. District heating is compatible with strategies to increase density in existing neighbourhoods and to develop higher density (67 du/ha to 94 du/ha) in future neighbourhoods.

In new neighbourhoods the viability of district heating will decrease as on the thermal efficiency of the housing units increases (as residential heating requirements decline). District heating will remain an important consideration until all new housing meets conserver-home standards. In existing areas, district heating systems may be more cost-effective than extensive retrofit.

District heating is understood as the centralized generation and distribution of heat in bulk to a number of buildings. The thermal energy is supplied by a central system fed by one or more plants. The heat transmission fluid, usually steam or hot water, is used for space heating, absorption cooling, domestic water heating and other purposes. Distribution of chilled water is referred to as "District Cooling." District heating has potential for cogeneration; that is, waste heat recovery from electricity production, incineration and industrial processing; as well as high overall efficiency in generating energy from all conceivable fuels.

The economics of district heating are dependent on the relative capital and operating costs of a centralized heat supply system as opposed to independent heating systems considering the following variables:

- the number of assured district heating customers;
- the capital costs for district heating including thermal plant, transmission system and, possibly, thermal storage; and the capital cost of independent systems;
- the availability of various fuels
- the amortization period;
- the cost of borrowing capital;
- the fuel costs for district heating and independent systems;
- the projected increase in fuel costs;
- the viability of cogeneration;
- the efficiencies of district heating and independent systems;
- the cost of labour for the district heating system; and
- the cost of maintenance and replacement for the district heating and independent systems.

District heating requires substantial capital investment for construction of a central plant and transmission system. The overall thermal efficiency of a district heating system is lower, however than independent condensing gas furnaces due to a lower

conversion efficiency and distribution losses. Cogeneration of heat and electricity more than doubles plant efficiency, producing energy savings of up to 50%. Dependence on a single fuel source is eliminated due to the feasible use of available local fuels and waste heat sources.

District heating systems produce large savings in fossil fuel use; thereby increasing Canadian energy security. Air pollution is significantly reduced in areas where oil is the predominant fuel and fire hazard in residences is reduced due to the use of flameless heat. Despite numerous benefits, the high capital costs of district heating systems suggest that subsidies or inducements will be necessary to encourage their use, since they will initially be less attractive to consumers than those independent systems which offer low capital costs and high levels of efficiency. Willingness of consumers to convert to district heating will depend on the relative prices of heat at the time of conversion and the cost to the consumer. All potential consumers must convert to ensure optimum system efficiency.

Examples

European Experience

District heating has been used in Northern Europe for over half a century and is demonstrating increasing economic and environmental advantages over conventional independent heating systems. Fossil fuels - coal, oil and natural gas - are the main sources of heat in North European systems. Due to the increasing cost and scarcity of such fuels, however, greater attention is being paid to cogeneration systems using refuse-fired incinerators and industrial waste heat boilers fired by sources such as pulp mill bark burners. District heating systems operating in conjunction with fossil-fuelled steam power plants have increased the efficiency

of fuel utilization approximately 143%. For 100 units of heat used in a cogeneration system, up to 20 units may be lost in the boiler and 5 in the distribution system, leaving 25 units of high grade energy in the form of electricity and 50 units of low grade district heat. Nuclear power stations have also been considered as district heating sources.

Due to their dependence on imported oil, Sweden, Denmark and West Germany lead in the development of district heating outside Eastern Europe and the Soviet Union. In Sweden about 35 towns have district heating systems.

The largest system, in Stockholm, serves only a small percentage of all city buildings but is one of the largest district heat and power systems outside the Soviet Union. The system incorporates temporary boilers serving new communities, regional heating plants and large heat and power generating stations. The Hogdalen refuse disposal plant producing electric power (15-20 MW) and hot water heat (60-70 MW) illustrates the use of alternative fuels in this system.

Four Swedish towns with populations between 80,000 and 100,000 have district heating systems serving more than 60% of their population. In Vasteras, 95% of all buildings are connected to the system. Shortage of capital funds has been the major obstacle to an even more comprehensive development of district heating in Sweden.

Various inducements, including direct government subsidies for retrofit connections and linking building permit approval to the connection of district heating, are applied to persuade customers to use district heating. New subdivisions or housing developments within reach of a district heating system are almost invariably connected from the start. Often a temporary oil-fired hot water boiler is utilized for several years until lines from the main plant are extended to the new area, or until the heating load

increases to a magnitude that can economically sustain a larger permanent heating plant. The temporary boilers then provide emergency standby or peak capacity requirements, or are moved to other new outlying subdivisions. Permanent heating plants, each serving a specific part of the community, are interconnected. Eventually heating demand can justify a large combined heating and power generating plant.

Swedish district heating systems generally use hot water at 99°C. Both back pressure and extraction condensing plants supply heat to these systems. In back pressure turbine plants, steam is expanded from boiler pressure to a pressure above atmospheric for the production of electricity with the exhaust steam supplying heat to the district heating system. The temperature of the exhaust steam must be high enough to provide useful heat to the system. In addition, the cost of heat distribution increases with decreasing temperature in the transmission medium. Extraction condensing turbine plants extract steam from the turbine for district heating at an intermediate state in the electrical generation cycle and the balance flows through lower pressure stages to the condenser. Whereas in back pressure plants electrical output is governed by heating requirements (since without heating demand there is no way of disposing of exhaust steam), in extraction condensing plants electrical output can be maintained if heating output is reduced. Independence of power and heat generation requires higher capital investment and a heat rejection system, with associated environmental problems.

North American Experience

Substantial sections of the downtown areas of New York, Philadelphia, Boston and Detroit are provided with central steam heat. Ottawa, Toronto, London and Vancouver also have district heating systems. Downtown Toronto is presently integrating a number of localized district heating systems in order to better utilize heat produced

from burning municipal waste. A similar proposal is being considered for the downtown areas of Ottawa and Hull. Urban renewal schemes coverting older power generating plants into sources of district heating are being considered in Halifax and Edmonton.

Municipal refuse is becoming an energy source for heat and power generation: district heating helps defray the costs of incineration now that, for ecological reasons, garbage is becoming less acceptable as landfill.

Mississauga, Ontario

Mississauga recently completed a downtown core study which projects a 20% energy saving through the use of district heating in the city. The density and street patterns of the core make this feasible, along with district cooling in summer which could result in a further 35% saving in energy.

Le Breton Flats, Ottawa, Ontario

Whereas steam or high temperature hot water is the principal transport medium in North American district heating systems, Le Breton Flats in Ottawa uses low-temperature hot water. Le Breton Flats is a demonstration project to find out how much energy can be saved with district heating as compared to conventional systems.

The district heating system is designed to provide 197 townhouses and apartments with space heating and hot water. The system uses a low-temperature hot water system with a gas-fired central boiler. Heat extracted in each residence is distributed by a forced-air system.

Shenandoah, Georgia

Shenandoah, Georgia, one of five developments monitored by the SAND program in the United States, determined that a central plant could conserve energy (through more efficient use of primary fuels), stabilize energy costs and accrue savings to residents. The preferred system used a small central utility plant phased to serve the site as development proceeded. The plant would produce thermal energy for heating and cooling, and electricity for power. Six fuel combinations were evaluated, including:

- fuel cell;
- internal combustion engine with heat recovery;
- wood-fired thermal;
- photo-voltaic;
- solar thermal central plant; and
- solar thermal/electric.

A wood-fired electrical co-generation system was the most suitable alternative. No cost/benefit details are available for this investigation.

Pickering, Ontario

Acres Shawinigan Limited evaluated four district heating alternatives and compared them with conventional, independent heating systems, assuming 50% of the consumers used natural gas and 50% used oil. They found that a combined district heating and power generation system, the least wasteful and most advanced technology available using fossil fuels, was not competitive with a single purpose centralized high-temperature water heating system. This was because the cost of the power produced by cogeneration was higher than the power rates in Ontario at the time of the study.

The theoretical study used Pickering, Ontario as a site and evaluated alternatives over a lifecycle of 40 years. Costs are indicated in Table 3. Despite higher capital costs, overall costs for the fossil-fuelled high-temperature (176°C) water heating system balanced conventional heating costs in 15 years, while the nuclear system needed 17 years. The projected cost of fuel for the fossil-fuelled system was two-thirds less than the conventional system in 1990, the nuclear fuel was five times less.

The projected overall costs for the fossil-fuelled system and nuclear cogeneration system were 43% and 24%, respectively, of the projected forty-year lifecycle costs for the independent systems. The nuclear alternative cost 56% of the conventional fossil-fuelled district heating system cost.

Northern Communities

District heating using cogeneration is a possibility for northern environments where imported fossil fuel is used in electricity generation and where utilidors typically supply heat as well as other services to buildings in a community.

Conclusions

The use of district heating to supply neighbourhood heating requirements should be carefully examined in terms of costs and benefits, compared to conventional independent heating systems. District heating has a more stable pricing (less responsive to fluxuations in energy prices) for space conditioning and domestic hot water heating; as well as the potential to use low-grade fuel sources rather than fossil fuels and electricity, which are more effectively used in other applications. In many cases, such as cogeneration using garbage incineration or nuclear plants, major benefits accrue in terms of combined efficiencies of operation.

TABLE 3

COMPARATIVE ANNUAL COSTS* - CONVENTIONAL AND DISTRICT HEATING

SOURCE: ACRES SHAWINIGAN (1976)

Year	Capital			Maintenance			Labour			Fuel			Pumping Distribution			Total		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1978	0.7	7.07	6.70	0.01	0.14	0.13	0.09	0.05	0.05	0.79	0.48	0.48	N.A.	0	0	1.59	7.74	7.15
1980	2.0	29.46	30.97	0.07	0.76	0.77	0.60	0.23	0.23	5.12	3.09	3.09		0.04	0.07	7.79	33.58	35.13
1982	3.4	34.32	36.08	0.21	1.55	1.62	1.70	0.55	0.55	13.34	8.10	8.09		0.10	0.18	18.65	44.62	46.52
1984	4.2	8.05	7.67	0.41	1.94	2.01	2.90	0.63	0.63	23.50	14.11	14.10		0.12	0.22	31.01	24.85	24.63
1985	5.5	2.82	2.58	0.55	2.13	2.18	3.90	0.80	0.80	30.59	18.31	18.38		0.14	0.25	40.54	24.20	24.20
1986	6.2	9.09	8.66	0.71	2.40	2.45	5.00	0.86	0.86	38.72	23.23	23.23		0.14	0.26	50.63	35.72	35.46
1988	7.5	48.46	218.16	1.12	3.79	7.96	7.80	1.39	1.39	58.66	35.09	15.56		0.23	0.41	75.08	88.96	243.48
1990	6.1	54.21	56.76	1.51	5.42	10.08	10.50	1.95	1.95	77.02	46.20	18.50		0.33	0.60	95.13	108.11	87.89
1992	5.6	13.02	12.39	1.95	6.46	11.57	13.80	2.23	2.23	98.34	59.07	18.67		0.33	0.59	119.69	81.11	33.29
1995	0	0	0	2.36	7.92	13.78	16.90	2.72	2.72	115.47	69.31	15.46		0.31	0.55	134.73	80.26	32.52
2000				3.23	11.11	18.43	23.70	3.83	3.83	150.90	90.59	20.16		0.34	0.60	177.83	105.87	43.02
2005				4.43	15.58	24.67	33.30	5.37	5.37	197.23	118.40	26.28		0.44	0.79	234.96	139.79	57.11
2010				6.07	21.85	33.01	46.70	7.54	7.54	257.78	154.74	34.27		0.57	1.03	310.55	184.70	75.85
2015				8.32	30.64	44.18	65.46	10.57	10.57	336.91	202.24	44.67		0.74	1.34	410.69	244.19	100.76
2020				11.40	42.98	59.12	91.82	14.82	14.82	440.34	264.32	56.85		0.97	1.75	543.56	323.90	132.54
2022				12.93	49.21	66.43	105.12	16.97	16.97	490.13	294.19	62.32		1.08	1.94	608.18	261.45	147.66

A - Conventional independent heating systems (50% oil, 50% natural gas)

B - Fossil-fuelled high-temperature water heating system.

C - Nuclear Cogeneration.

* Millions of Dollars

The high capital costs of district heating systems and transmission heat losses which reduce efficiency are more than counterbalanced by fuel savings and energy security over the life of the system.

1. District heating can save 50% to 75% of the cost of space conditioning (heating and cooling) and domestic hot water heating over a lifecycle of 40 years, assuming use of the most economical fuel alternative.

2. District heating should be used in conjunction with medium density (67 to 94 du/ha) housing. Compact development improves heat transmission efficiencies. Mixed use development with different peak demands also improves energy efficiencies.

   The thermal density of housing is also an important consideration in evaluating the viability of district heating. District heating should not be used with conserver homes except in special locations, such as the North.

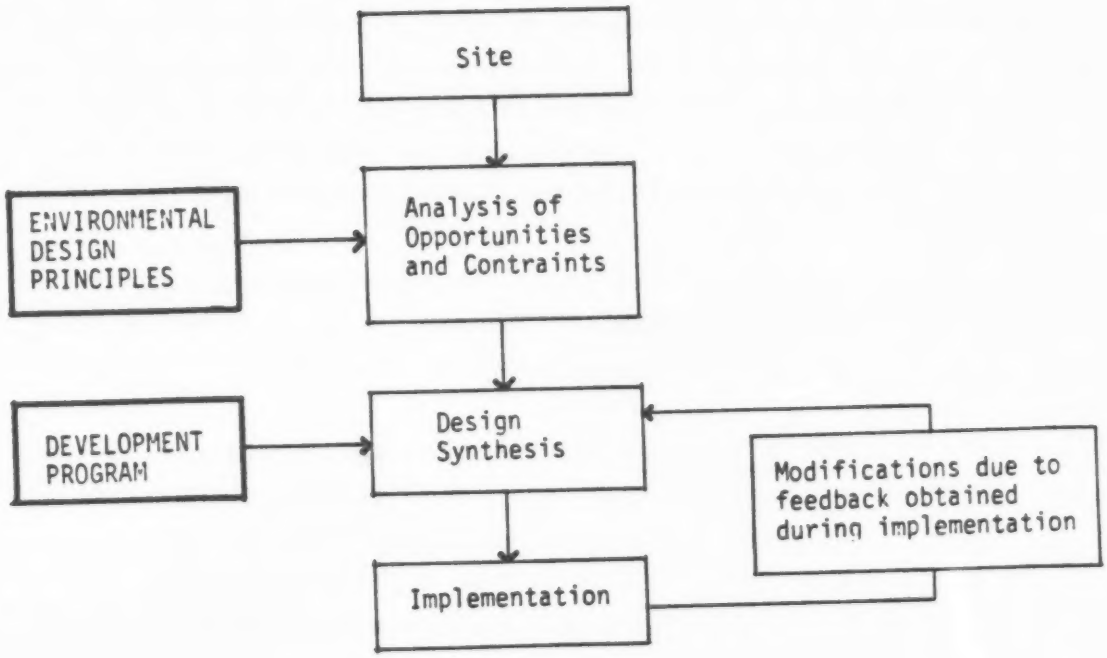
3. The district heating system should be tailored to local opportunities including local energy sources such as fossil fuels, nuclear, solar and biomass, and cogeneration with electricity generation or industrial uses. Cogeneration of electricity can improve fuel use by 50%.

4. District heating should use flexible systems which accommodate community growth and change. Portable plants might be used in new developments until a permanent district heating plant is economical.

4. ENVIRONMENTAL DESIGN

Environmental design practices can save significant amounts of the energy required for site development and for site maintenance, residential space heating and cooling, water heating, lighting and transportation. Embodied energy, or the energy used to

Figure 13: ENVIRONMENTAL DESIGN



construct roads, buildings and landscaping, can be reduced 15% to 25%; while operational energy, the energy used to heat and cool residences and run cars, can be reduced 10% to 50%. Most embodied energy savings are expressed in terms of cost savings.

Principles

Environmental design seeks the best fit between a site and the site development program, including site and building design, in order to maximize the suitability and minimize the impact of new development. This process of achieving a good fit between the development program and the site involves three major stages (Figure 13); analysis, synthesis and implementation:

1. Analysis of site development opportunities and constraints, such as geotechnical, climatic, solar, topographic, biotic and cultural opportunities and constraints;

2. Design synthesis, fitting the development program to the site opportunities and constraints with consideration of cost and energy use constraints;

3. Implementation of the site plan and engineering design ensuring that construction practices respond to site conditions and minimize impact.

Determination of the site opportunities and constraints requires a site survey and analysis, and mapping of general constraint factors. Geotechnical factors affecting engineering and foundation costs are especially important in residential development. These include soil type, permability, bearing capacity, slope stability, surficial geology, bedrock geology, groundwater hydrology and surficial drainage patterns. Climate, topography, vegetations and cultural features are other important site development considerations.

Tailoring the development program to the site through the design synthesis requires tradeoffs between development objectives and site conditions. Objectives of the design synthesis include:

- overall planning to maintain existing landforms, slopes, drainage patterns and vegetation, thereby reducing the energy expended in stripping vegetation and topsoil, earthwork, erosion control and future landscaping;
- specific siting of buildings and roads to minimize cut and fill;
- keeping road and utility lines short to minimize site disruption;
- siting buildings to use existing vegetation and topography as buffers against cold winter winds and as channels for cooling summer breezes; and
- considering the effect of vegetation and topography on siting buildings for solar access.

Construction practices which minimize earth moving and soil exposure, and reduce erosion through diverting and slowing runoff, save energy both in site development operations and in the preservation of topsoil which would otherwise have to be imported. Similarly, maintaining areas of existing vegetation through careful construction management will reduce future landscaping requirements.

Examples

Environmental design is a process through which small incremental expenditures for site analysis and development planning produce significant cost and energy savings.

Burke Center Community

A study in Burke Center Community, Virginia (Tables 4 and 5) compared energy-conserving and conventional plans on the same parcels in terms of site development costs and residential, commercial and recreational energy use.

The study was carried out under the auspices of the Site and Neighborhood Design (SAND) Program of the U.S. Department of Energy. The energy-conserving test parcels produced an overall saving of 24% in land development costs. The principal savings were in paving, earthwork and utility line reductions, and are easily related to energy savings (Table 6).

The Burke Center energy-conserving plan reduced residential energy use, including space heating and cooling, water heating, lighting and appliances, by 35% (Table 7). This was achieved through the application of energy-saving techniques appropriate to the particular site and context. A specialized technical team pre-selected the following techniques for Burke Center:

- building orientation for sun and wind effects;
- clustering and consolidation of structures for sun and wind control, and overall reduction of exterior wall areas;
- natural screening with earth berms and vegetation;
- water-to-air heat pumps, and
- water saving devices.

The energy conserving plan also reduces transportation energy requirements through development of a more efficient circulation system.

The Burke Center SAND study also indicated that maximum yield and maximum profit are not always synonymous. In one test parcel, a 3% reduction in the number of dwelling units proposed in the conventional plan was outweighed by development cost savings of 36% in the energy-conserving plan (Table 8).

Radisson, New York

In Radisson, New York (Tables 9, 10 and 11), SAND energy-conservation plans incorporated passive site design features similar to those of Burke Center, including:

TABLE 4: BURKE CENTER: CLIMATIC DATA

CLIMATE INFORMATION

General: Continental

Degree Days

Heating	2766
Cooling	504

Average Temperature:

Yearly	12.1°C
Winter	[illegible]
Summer	[illegible]

2.5 Percent Design Temperature:

Winter	[illegible]°C
Summer	32.8°C dry bulb and 23.3°C wet bulb

Average Wind Velocity:

Winter	16 km/h (NW)
Summer	13 km/h (W-S)

Average Rainfall: 89 cm/yr

Average Snowfall 61 cm/yr

Solar Gain 402 kJ/m^2/day

Annual Average Sunshine: 2,280 hr.
(52 percent of possible)

TABLE 5: BURKE CENTER: PROJECT DATA
(CONVENTIONAL PLAN)

LAND USE INFORMATION

Site Area: 563 hectares

Dwelling Units:

Completed	1,500
Total Planned	5,452

Gross Density: 9.7 du/ha

Parking:

Each dwelling (including garden and midrise units) has 2 off-street parking spaces. [1]

LAND USE PLAN

Land Use

	Hectares	Percent
Residential	423	75
Industrial	25	4
Commercial	21	4
Schools	6	1
Major Open Space [2]	88	16
Total	563	100

ECONOMIC INFORMATION

Site Cost: Approximately $23,475/ha
Site Improvement Cost: [3] $25,000,000
Construction Cost: [4] $215 to $376/m²
Amenities Cost: $550/unit [5]
Homeowner Association Dues: $240/yr [6]

TABLE 5 (cont'd): BURKE CENTER: PROJECT DATA
(CONVENTIONAL PLAN)

RESIDENTIAL UNIT INFORMATION

Unit Type	No.	Unit Size (Sq. m²)	Lot Size (Sq. m²)	1980 Price
SFD	1,193	167-279	520-743	$ 71,000-134,000
Patio/Duplex	2,450 [8]	111-204	371-743	63,000-89,000
Townhouse [9]		102-204	279-650	58,000-90,000
Garden [10]	1,509			
Mid-Rise [10]	300			

NOTES:

1. Standard required by Fairfax County.
2. Includes the major open space and stream valley system. Additional open space is contained in the above gross parcels, bringing the total to approximately 121 hectares.
3. Includes planning, engineering, streets constructed by developer, grading for these streets and for amenities, and water and sewer lines to finished lots and to parcels in which unfinished lots are sold.
4. Varies widely because of the different builders involved.
5. This fee paid by builders to Burke Centre Partnership includes all amenities and recreastion development.
6. Includes use of all community-wide open space, administration, and garbage collection, but not private street and cluster open space management.
7. The 520 m² lot fronts on a 21.3 m private street space and backs on a 12.2 m wooded common buffer.
8. Includes units under "Townhouse," the following item in the table.
9. Townhouse units are included in total for "Patio/Duplex," the preceding item.
10. As of this study, no garden or mid-rise apartments have be constructed.

TABLE 6: BURKE CENTER: SITE DEVELOPMENT COSTS

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY PLAN	PERCENT SAVING
	Total Cost ($000)	Total Cost ($000)	Per Item
Site Preparation	351	358	- 2
Earthwork	2,651	1,537	42
Erosion Control	55	49	11
Site Drainage	669	545	19
Sanitary Sewer	526	424	19
Water Line	535	372	30
Pavement	3,547	3,045	14
Curb/Gutter	687	345	50
Shade Trees	246	375	-34
Evergreen Trees	10	15	-33
Shrubs	27	27	0
TOTAL	9,304	7,092	24

Source: Urban Land Institute, 1981.

TABLE 7: BURKE CENTER: OPERATING ENERGY USE

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY PLAN	ENERGY PLAN PERCENT SAVINGS
	Total Energy Use (10^9 KJ/yr)	Total Energy Use (10^9 KJ/yr)	Per Item
Heating, ventilation, air conditioning, lighting, appliances and hot water	144.6	99.4	31.3
Transportation: on-site	101.5	98.5	3.0
off-site	381.1	374.9	1.6
Potable Water Treatment	15.9	9.1	42.8
Wastewater Treatment	28.6	16.4	42.7
Refuse Collection and Disposal	3.1	1.8	41.9
TOTAL	674.8	600	
	(10^9 KJ/m^2/yr)	(10^9 KJ/m^2/yr)	
Residential Operational Energy Use Index*	545,591.9	369,167.7	35

*Includes HVAC equipment, lighting, hot water heating and pumping energy uses.

Source: Urban Land Institute, 1981.

TABLE 8: PARCEL 22, BURKE CENTER COST SAVINGS DUE TO ENVIRONMENTAL DESIGN

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY CONSERVING PLAN	PERCENT SAVINGS
Number of Dwelling Units	424	410	- 3%
Development Cost	$2,541,000	$1,570,000	36%

TABLE 9: RADISSON: CLIMATE INFORMATION

General: Humid continental

Degree Days

Heating	3692
Cooling	288

Average Temperature:

Yearly	8.9°C
Winter	2.8°C
Summer	21.7°C

2.5 Percent Design Temperature:

Winter	-17.8°C
Summer	32.2°C

Average Wind Velocity: 15.9 km/h ranging over a 60° north/northwest arc (in winter)

Mean Rainfall: 92.5 cm [1]

Solar Gain 300 Langleys

Annual Average Sunshine:

November through March -- less than 40 percent

May through August -- up to 65 percent

1. Rainfall is distributed evenly throughout the year, averaging about 7.6 m per month. On about 168 days a year precipitation exceed 0.025 cm. The mean annual snowfall is 254 cm and monthly amounts in excess of 61.0 cm are not uncommon.

TABLE 10: RADISSON: PROJECT DATA

UNIT INFORMATION

Type	Unit Size (in m^2)	Lot Size (in m^2)	Number	Lot Price	Sales Price
Single-Family Detached	134-212	836-1022	135	$ 12,000	$ 71,000-90,000
Townhouse	127.6	418	66	1,000	45,000
Multifamily	-	-	142	-	-

DEVELOPMENT CHARACTERISTICS OF RESIDENTIAL STUDY SITE

	Conventional Plan	Energy Plan #1	Energy Plan #2
Total Number of Dwelling Units	201	259	220
Gross Site Denisty (Units/ha)	6.35	8.15	6.92
Unit Distribution:			
Single-Family Detached	135	--	116
Single-Family Cluster	--	132	32
Town House Conventional	66	--	72
Town House Cluster	--	127	--
Total No. of Protected Units	64	193	168
Public Road Length (m)	2,804	2,377	2,652
Private Roadways (m)	533	1,228	671

* Private Roadway includes developed for flag lots on conventional plan, as well as cluster housing.

TABLE 11: RADISSON: SUMMARY OF INCOME PER LOT

ITEM/DESCRIPTION	CONVENTIONAL PLAN (201 D.U.)	ENERGY PLAN#1 (259 D.U.)	ENERGY PLAN #2 (220 D.U.)
Income Per Lot Type			
Single-Family	$1,620,000 (135)	$1,584,000 (132)	$1,776,000 (148)
Townhouse	396,000 (66)	762,000 (127)	432,000 (72)
Total Site Income	$2,016,000	$2,346,000	$2,208,000
Average Income Per Lot	$ 10,029	$ 9,057	$ 10,036
Total Site Income Increase	(n.a)	$ 330,000	$ 192,000
Profit Per Lot Increase	(n.a)	$ 1,274	$ 872

ECONOMIC INFORMATION

Site Cost: $1235/ha (1968)
$2471/ha (1979)

Site Improvement Costs: Approximately $9,600/unit (conventional)

Construction Costs: $125/m² (residential)

- building orientation at a 90° angle to the prevailing winter winds;
- buffering of winter winds by vegetation, unit clusters and solid fences;
- selection of sites on slopes that maximize solar radiation (southeastern being considered most desirable);
- orientation of the largest window areas on structures to maximize solar exposure in the heating season and minimize mechanical heating and cooling requirements, and
- clustering of single-family attached and detached units on private drives to optimize wind protection and solar orientation.

Mechanical systems which would heat, cool and provide domestic hot water to the Radisson units included three alternatives: independent systems such as air-to-air and groundwater heat pumps, and solar panel and thermal storage for individual buildings; cluster systems, and a central plant system.

An important consideration of the Radisson energy-conservation plans was reducing winter heat loss through siting buildings to minimize windward wall exposure. The model simulated reduced heating loads due to wind protection, and identified annual energy savings for the modelled units of between 6% and 9% for single-family detached units and up to 13% for townhouse units. An overall comparison of an energy-conserving plan with the conventional site plan (Tables 12 and 13) indicated that 70% of the north and west surface wall exposure on the conserving plan is sheltered from the winter wind compared to 20% on the conventional plan. The distribution of surface walls by orientation indicated that the energy conserving plan reduced north wall exposure by 2% and east/ west wall exposure by 37%. Prevailing winter winds are from the north west in Radisson, with an average speed of 16 km/h. Radisson has 3,692 heating degree days and 288 cooling degree days, annually (Table 9).

TABLE 12: RADISSON: MODELLING OF WIND PROTECTION AND ENERGY SAVINGS

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY CONSERVATION PLAN
Percent Protected North and West Wall Areas	20	70
Percent Energy Savings	0	9 - 13

TABLE 13: RADISSON: HOUSING UNIT OPERATING COSTS
DUE TO WIND EXPOSURE

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY PLAN #1	ENERGY PLAN #2
	Operating Costs ($)	Operating Costs ($)	Operating Costs ($)
Overall Operating Costs			
unprotected units	54,468	25,938	20,581
protected units	22,695	69,163	61,107
TOTAL	77,163	95,101	81,688
Number of Units			
unprotected	137	66	52
protected	64	193	163
TOTAL	201	259	220
Operating Costs Per Unit	383.9	367.2	371.3
Percent Energy Savings	0	4.4%	3.3%

TABLE 14: RADISSON: RESIDENTIAL DEVELOPMENT
COST COMPARISON

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY PLAN #1	ENERGY PLAN #1	ENERGY PLAN #2	ENERGY PLAN #2
	Total Cost ($)	Total Cost ($)	Percent Savings	Total Cost ($)	Percent Savings
Roads/Driveways					
Overall Plan	593,000	530,000	10.6	577,000	2.7
Per Unit	2,950	2,046	30.6	2,622	11.1
Water					
	238,000	236,000	0.8	231,000	2.9
	1,184	911	23.1	1,050	11.3
Sanitary Sewers					
	425,000	462,000	- 8.7	420,000	1.2
	2,114	1,784	15.6	1,909	9.7
*Drainage: Piping					
	160,000	291,000	81.9	177,000	10.6
Ditching					
	52,000	52,000	0	52,000	0
	259	201	22.4	236	8.9
Walkways					
	225,000	225,000	0	225,000	0
	1,119	869	22.3	1,023	8.6
Contingencies					
	253,950	269,000	- 5.9	252,300	0.8
	1,263	1,038	17.8	1,146	9.3
TOTAL OVERALL	1,946,950	2,065,000	- 6.1	1,934,300	0.6
PER UNIT	9,686	7,973	17.7	8,792	9.1

*Difference in cost between piping and ditching operations is due to increased pipe size for energy plans required because of increased density.

TABLE 15: RADISSON: RESIDENTIAL EMBODIED ENERGY COMPARISON

ITEM/DESCRIPTION	CONVENTIONAL PLAN	ENERGY PLANT #1	ENERGY PLAN #1	ENERGY PLAN #2	ENERGY PLAN #2
	Total Energy Use (10^6 KJ/yr)	Total Energy Use (10^6 KJ/yr)	Percent Savings	Total Energy Use (10^6 KJ/yr)	Percent Savings
Road/Driveways					
Overall Plan	8,415	7,967	5.3	8,320	1.1
Per Unit	42	31	26.2	38	9.5
Water					
	4,513	3,904	13.5	4,450	1.4
	24	15	37.5	20	16.7
Sanitary Sewers					
	3,624	3,693	- 1.9	3,502	3.4
	18	14	22.2	16	1.1
*Drainage: Piping					
	3,891	4,959	-27.4	3,222	17.2
	19	19	0	15	21.1
Ditching					
	30	30	0	30	0
	0.15	0.12	20.0	0.14	6.7
Walkways					
	633	633	0	633	0
	3	2	33.3	3	0
Contingencies	3,165	3,177	- 0.4	3,023	4.5
	16	12	25.0	14	12.5
TOTAL: OVERALL PLAN	24,271	24,361	- 0.4	23,180	4.5
PER UNIT	122	93	23.8	106	13.0

*Difference in cost between piping and ditching operations is due to increased pipe size for energy plans required because of increase density.

Figure 14: SUMMARY OF SITE COST AND ENERGY SAVINGS DUE TO THE APPLICATION OF ENERGY CONSERVATION TECHNIQUES IN BURKE CENTER AND RADISSON

a) Site Development

Item/Description	Site Development Costs	- Percent Savings +
	Total Cost ($)	
Burke Center		
Conventional Plan	9,304,000	
Energy Plan	7,092,000	24
Burke Center Parcel 22		
Conventional Plan	2,541,000	
Energy Plan	1,570,000	38
Radisson		
Conventional Plan	1,946,950	
Energy Plan #1	2,065,000	6.1
Energy Plan #2	1,934,300	0.6
	Cost per D.U. ($)	
Burke Center Parcel 22		
Conventional Plan	5,993	
Energy Plan	3,829	36
Radisson		
Conventional Plan	9,686	
Energy Plan #1	7,973	17.7
Energy Plan #2	8,792	9.1

b) Embodied Energy Use

Item Description	Embodied Energy Use	- Percent Savings +
	Total Energy Use 10^6 kJ/yr	
Radisson		
Conventional Plan	24,271	
Energy Plan #1	24,361	0.4
Energy Plan #2	23,180	4.5
	Energy Use Per D.U.	
Radisson		
Conventional Plan	122	
Energy Plan #1	93	23.8
Energy Plan #2	106	13

c) Operating Energy Use/Cost

Item/Description	Operating Energy Use	Percent Savings
	Residential Operational Energy Use Index (10^6 kJ/m^2/yr)	
Burke Center		
Conventional Plan	545,591,900	
Energy Plan	369,167,700	35
	Operating Energy Use 10^6 kJ/yr	
Burke Center		
Conventional Plan	674,800	
Energy Plan	600,000	11
	Operating Costs Total Cost ($)	
Radisson		
Conventional	77,163	
Energy Plan #1	95,101	23
Energy Plan #2	81,688	5.8
	Cost Per Unit ($)	
Radisson		
Conventional	383.90	
Energy Plan #1	367.20	4.4
Energy Plan #2	371.30	3.3

Radisson produced overall savings per unit in site development costs for each alternative energy plan (Tables 14 and 15). Although overall costs were 6% higher for Energy-Conserving Plan #1 and less than 1% lower for Plan #2, development costs per unit were respectively 17% and 9% less than the conventional plan. Approximately the same embodied energy (± 5%) was consumed in each of the plans, but on a dwelling unit basis, embodied energy decreased by 22% and 12% in Energy-Conserving Plans #1 and #2, respectively. Embodied energy is the amount of energy expended to manufacture and put building and infrastructure materials and systems in place. The developer increased his profit per lot $1,274 in Energy-Conserving Plan #1 and $870 in Plan #2 while reducing operating costs per unit (Table 11). The savings due to the application of energy conserving techniques in Burke Center, Virginia and Radisson, New York, are summarized in Figure 14.

Guelph, Ontario

Sheltering can have a major impact in high wind situations. For a detached unit in Guelph, Ontario (Ontario Ministry of Housing, 1980) Ontario heat losses were 19.4% greater with a 11 km/h wind than no wind and 38.3% greater with a 24 km/h wind.

Conclusions

Environmental design recognizes that every development is unique. Physical conditions such as size and shape, geotechnical factors, climate, topography, vegetation and cultural features vary between individual sites, and so do development programs, according to the developer's objectives, market trends, development regulations, and technical know-how. The following approaches have demonstrated energy savings under a variety of conditions.

1. Environmental design practices will produce savings in the order of 15% to 25% of embodied energy in areas with physical constraints such as steep slopes, dense vegetation or existing structures.

2. Operation of equipment for grading, demolition or clearing can be reduced through revisions to lot layout and grading, and incorporation of existing structures into the plan. Cleared trees may be used as firewood.

3. Use of open space as natural drainage channels; reducing runoff through the use of on-site percolation basins, and use of permeable paved surfaces will all serve to avoid equipment operation and use of materials (embodied energy) for stream channelization, water control structures and other storm drainage improvements.

4. Preservation of existing vegetation may be in the form of managed wood lots in open space areas. These can serve as alternative fuel sources.

5. Embodied energy for construction of streets and utilities will be reduced through efficient site design minimizing lengths of streets and utility lines.

6. Building siting in areas with favorable microclimate will save operational energy. Siting buildings in areas with south-facing slopes, protection from winter winds and access to summer breezes will save 10% to 35% of operational energy requirements.

7. Microclimate conditions may be improved through the following measures:

- orienting lots and buildings to the south or southeast;
- providing wind breaks against winter winds;
- planting street trees;
- imposing lot coverage restrictions for unshaded paved surfaces;
- using water areas for climate modification;
- providing a manual for lot buyers on proper orientation and landscaping.

8. Use of energy-efficient building materials, especially local materials, will reduce the consumption of embodied energy.

9. Energy required to maintain landscaping through mowing or irrigation will be reduced by keeping lawn areas to a minimum and selecting low-maintenance, climate adapted plantings. Maintaining existing areas of vegetion has the same effect.

5. PASSIVE SOLAR

Passive solar energy can contribute 10% to 40% of building space heating requirements depending on housing quality, siting and location. However, unless the cost of achieving this gain is minimal, solar heating is less important than other neighbourhood-level energy conservation techniques. Solar energy design is an extra cost to developers and builders and does not have strong market attraction. Implemention of passive solar principles requires government regulation and incentives.

Gough (1979) indicates that passive solar gain through the window areas of the existing stock of residential building accounts for 12.5% of the gross annual residential heating energy requirement. This means solar heat gain presently accounts for 2.26% of Canada's total annual energy consumption. Proper window planning can significantly increase this total.

Figure 15: AZIMUTH AND ALTITUDE

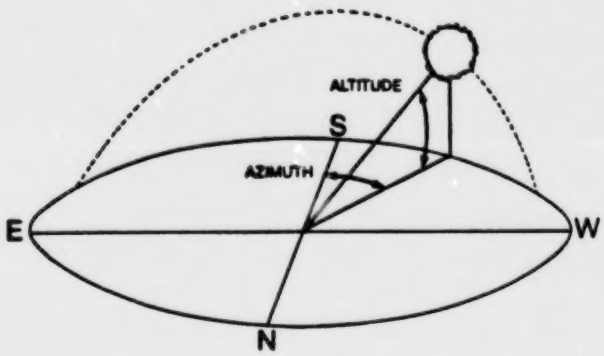
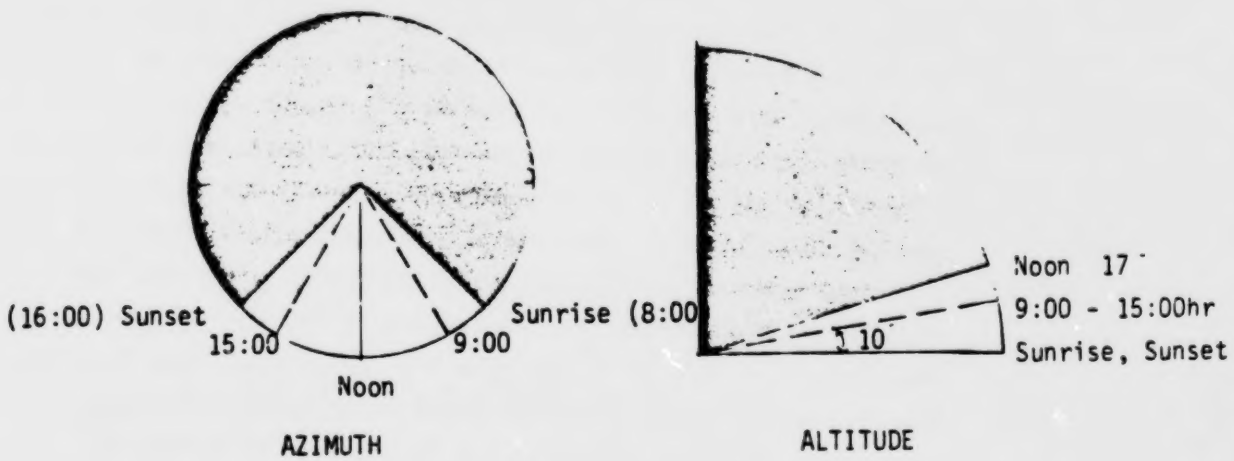


Figure 16: CRITICAL HOURS OF SUNSHINE



(Data for 50° N latitude, December 21)

Principles

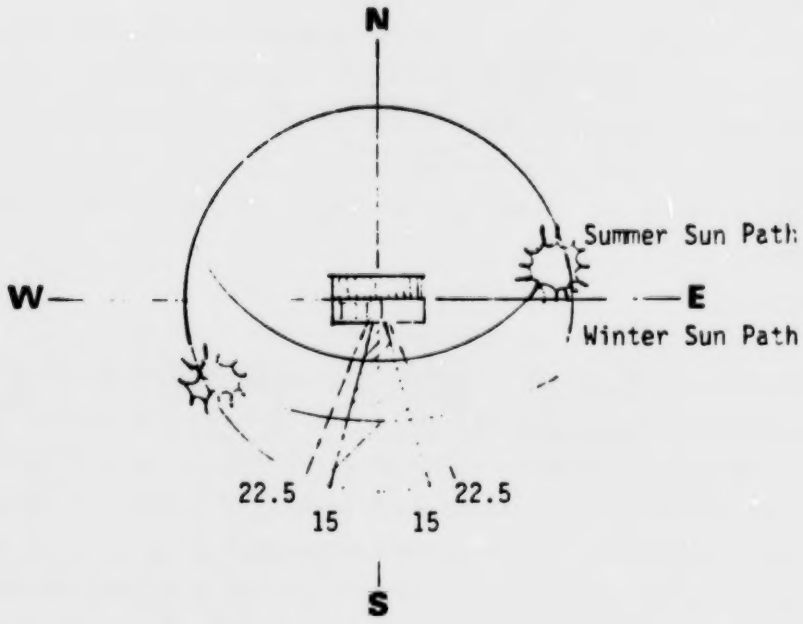
As the thermal efficiency of the building envelope is improved the actual marginal contribution of environmental design for solar orientation, buffering winter winds and channelling summer breezes becomes less significant. This is because the heating season of an airtight, super-insulated house is much shorter (three months) than for a conventional house (six months). Thus additional costs incurred in the collection of solar energy or in wind buffering are balanced against very small incremental energy savings.

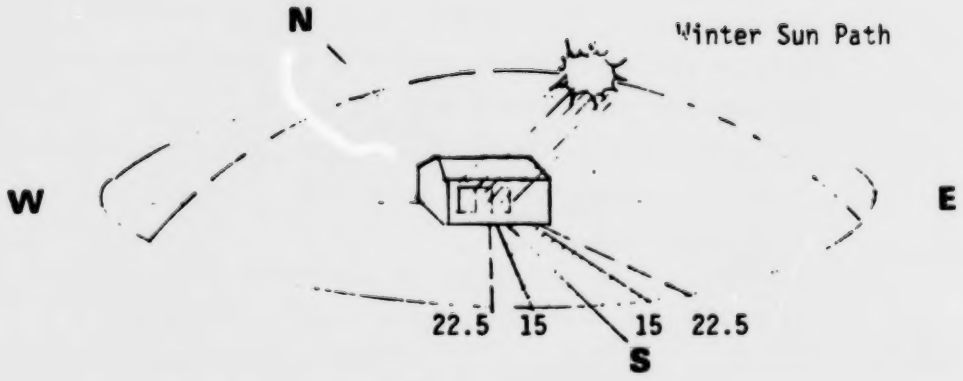
Passive solar systems include direct gain systems, with incremental costs up to 10% of the cost of building construction ($6,000), and Trombe wall and water wall systems, which add 5% to 12% ($3,000 to $7,200) to residential construction costs. The direct gain system is the simplest and most commonly used system.

During the heating season the direct gain system allows sunlight to enter a building directly through sun oriented windows or skylights. When sunlight impinges on floors and walls, part is absorbed and stored as thermal energy, while part is converted directly to heat. If the structure is properly designed for passive solar heating, the floors, walls and ceilings will reach a maximum temperature of between 26° and 27°C. When the room temperature drops below the temperature of the thermal mass or when people or objects in the room are cooler than this temperature, the floors, walls and ceilings act as large low-temperature radiators. Radiant heating is one of the most efficient and comfortable means of heat transfer.

Housing which uses direct gain solar heating requires correct window orientation and unobstructed solar skyspace within the critical hours of sunshine - 9:00 hr. to 15:00 hr. - during the heating season. This is the period in which the sun has an

Figure 17: OPTIMUM SOLAR ORIENTATIONS





altitude of 10° or more above the horizon and is suitable for passive solar heating in the coldest months (Figures 15 and 16). At a latitude of 44° North, 90% of the sun's useful energy occurs between 9:00 and 15:00. At higher latitudes this period of useful sunshine gets shorter. Solar gain is possible up to 59°N and is most useful during the spring and fall (See Energy Zone Map).

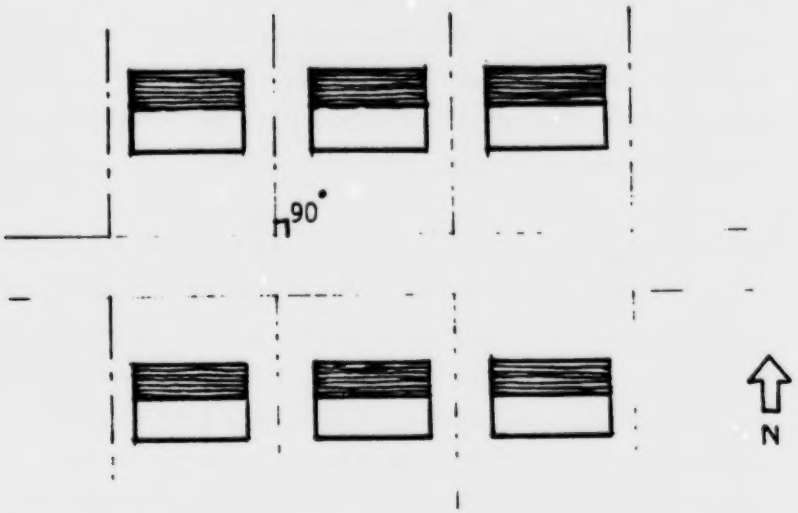
Although optimum solar orientation varies according to climate zones, the optimum in Canada is generally south or within 15° east of south. Orientations up to 22.5 degrees east or west of south will achieve substantial solar gain (Figure 17). The Frankel/Lambert Townhouse Development in Toronto, Ontario measured 45% higher solar gains in south-oriented units than in east or west facing units. This reduced heating fuel requirements in south facing units by an estimated 12.5 %.

Proper solar orientation for direct gain heating requires consideration of street and lot layout, building siting, and building design including:

- east-west street orientation to ensure that standard lotting is oriented south or within 15° of south;
- lot orientation through the use of angled lot lines, flag lots or corridor lots to ensure south orientation where streets are not oriented east-west;
- building setbacks and building height and design to ensure that buildings do not block the solar skyspace of other residences, and
- building siting and design to orient the greatest area of windows south while minimizing other window areas.

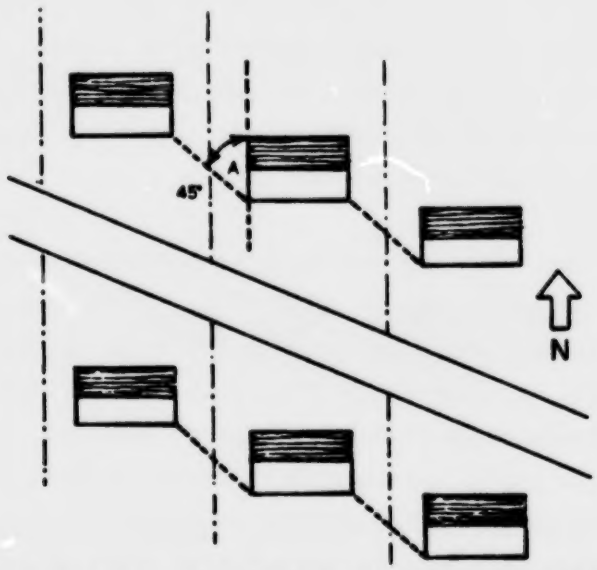
Since conventional lotting in subdivisions is perpendicular to the streets, good solar orientation is ensured by running local streets east-west, or 15° north or south of east-west. This is the most commonly implemented solar design technique at the neighborhood scale and is used in solar subdivisions from California to Ontario.

Figure 18: LOT ORIENTATION ON EAST-WEST STREETS



Source: Erley and Jaffe, 1979.

Figure 19: LOT ORIENTATION ON INTERCARDINAL STREETS



Maintaining south orientation of housing where streets are shifted from the east/west axis. Angle A is formed by the intersection of north/south with a line connecting the southwest corner of one house to the southeast corner of its western neighbor.

Source: Erley and Jaffe, 1979.

Solar orientation regulations requiring a minimum proportion of east-west streets in future subdivision must permit exceptions, however, to account for other potentially conflicting energy conservation strategies; for example, designing in reponse to topography which slopes from east to west.

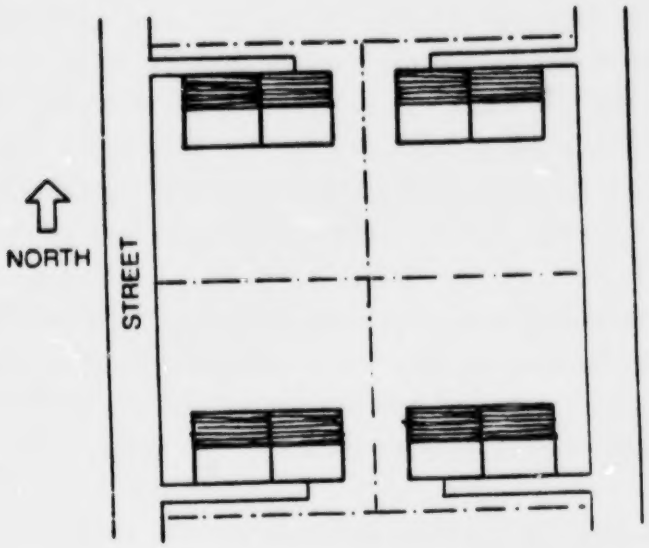
Solar access may also be affected by decreasing right-of-way widths. This could affect the solar setbacks between residences across the street from one another. Wide streets and rights-of-way cost more to construct and maintain, cause excess runoff and increase summer air temperature. If a contemplated reduction in street width had a negative impact on solar access, then other measures, such as increasing front yard setbacks, might be employed to ensure solar opportunities.

Where subdivision regulations require lot lines perpendicular to streets, the orientation of lots will be governed by street orientation as opposed to solar access requirements. On east-west streets this ensures optimal solar access and flexibility in building siting; however, where the street axis shifts to a north-south or intercardinal direction, perpendicular lot lines often mean poor orientation.

Streets running southeast to northwest with perpendicular lot lines will lead to residential overheating in summer. A better approach would be to angle lot lines to the street so that their axis is north-south (Figure 18 and 19), taking care that residences do not shade each other's solar skyspace. A simple check is to draw the 45 degree azimuth lines defining solar skyspace to ensure that buildings are not shading the south-facing walls of their neighbors in the critical hours of heating.

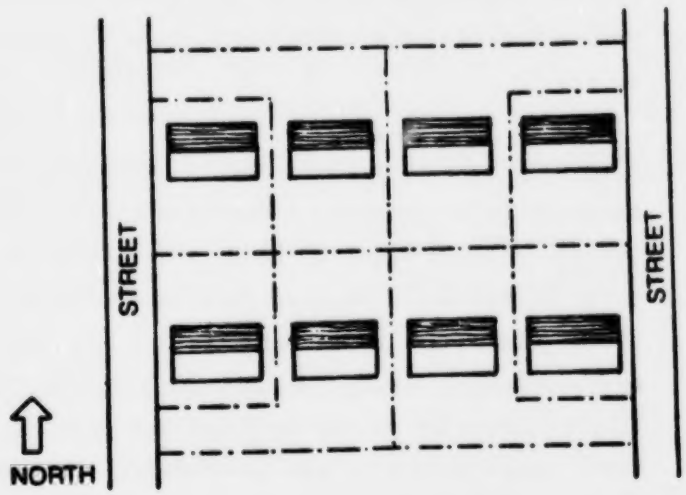
Solar orientation of lots on north-south streets, or on intercardinal streets along which lots cannot be angled, can be maintained by combining lots, using flag or key lots and increasing

Figure 20: COMBINING LOTS FOR PROPER ORIENTATION



Source: Erley and Jaffe, 1979.

Figure 21: USING FLAG LOTS FOR PROPER ORIENTATION ON NORTH-SOUTH STREETS



Source: Erley and Jaffe, 1979.

lot frontage (Figures 20 and 21). The first is especially useful where lot layout has already been dictated: two lots abutting north and south can be combined and buildings sited close by each other along an east-west axis. This could necessitate use of semi-detached or unconventional housing forms and additional provisions to city subdivision standards or zoning by-laws. The flag or corridor access works in a similar fashion but with a designated access corridor from the interior lot to the street. Key or chevron lots are a variation on this theme with the house in one corner of the "L" shaped lot and with "front" yards at right angles to rear yards.

Regulating building setbacks on lots which are oriented east-west or intercardinally will allow residences to at least experience southern exposure for part of the day (Figure 22). This approach, using PUD or zero lot line regulations, may be the only one that can be used to gain some of the benefit of solar access with certain site constraints such as easterly sloping topography.

Building setbacks on lots are important even on conventional north-south lots (Figure 23). If south entry units do not have uniform front yard setbacks and north-entry units, uniform rear yard setbacks, then certain houses will lose part of their solar access.

Alternative housing types may be necessary in some cases to maximize solar access. A performance standard requiring a certain minimum level of solar orientation for lots promotes solar access while leaving developers and planners the freedom to choose their own layout for streets, lots and buildings. The major disadvantage of this approach is the extra administrative time required in reviewing plans and applications to determine their compliance with the performance standards.

Figure 22: UNIFORM VERSUS STAGGERED SETBACKS ON NORTH-SOUTH STREET

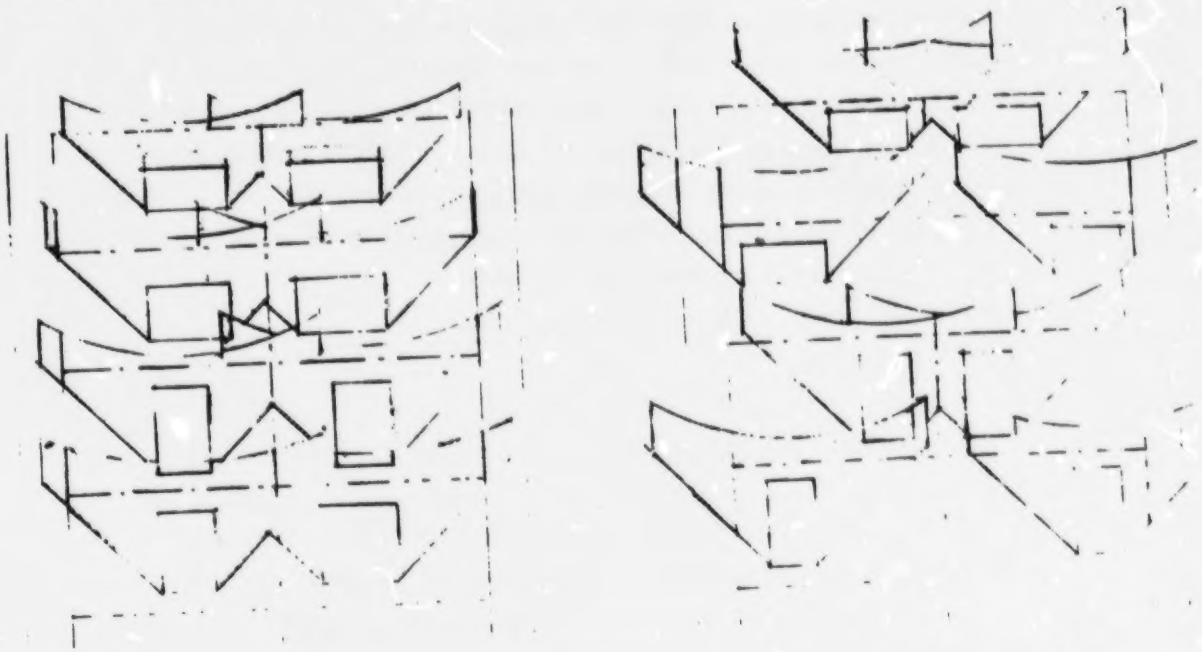
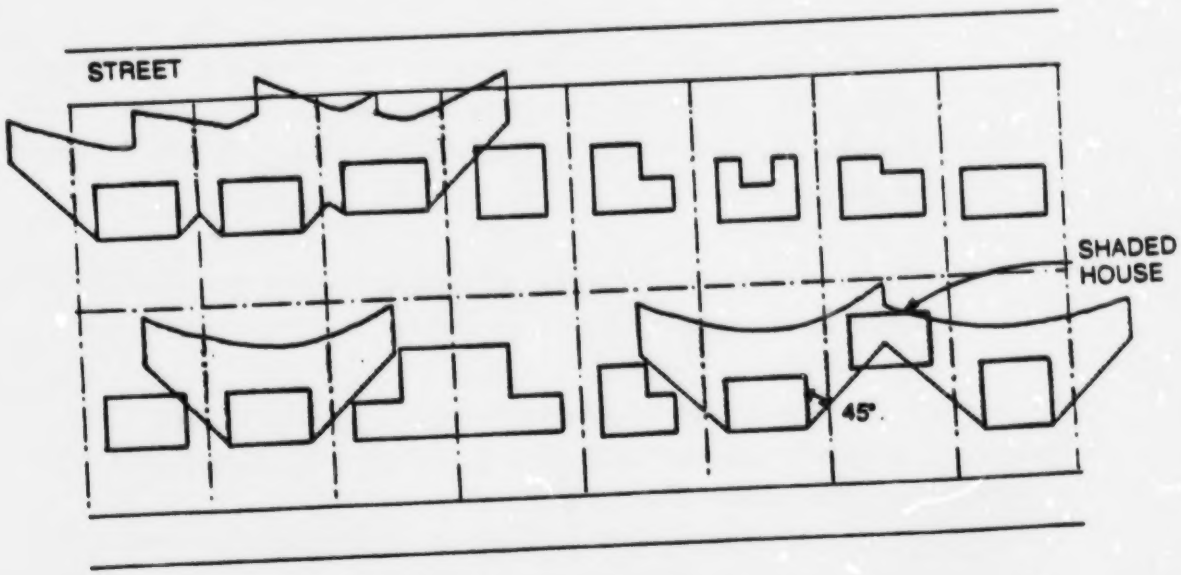


Figure 23: UNIFORM VERSUS STAGGERED SETBACKS ON EAST-WEST STREET



Landscaping also affects solar access. If a municipality requires boulevard tree plantings and site landscaping, the landscape plan should meet guidelines affecting solar access. An ideal energy plan would develop coniferous buffer plantings to screen cold winter winds, and deciduous plantings to shade surfaces and south-facing walls in the summer, while allowing sun penetration in the heating season.

Examples

Sacramento, California

In late 1977 Sacramento, California adopted a resolution that new lots and residences be oriented for maximum effective use of passive solar energy. All new developments are evaluated for their solar orientation based on a performance standard for the orientation of lots. The long axis of all lots should be within 22.5 degrees of true north. The resolution made generous provisions for exceptions.

Alliance Subdivision, Brampton, Ontario

The Alliance Subdivision in Brampton, designed under the Brampton Energy Conservation By-Law, makes changes in the conventional approach to subdivision design to save homeowners an estimated 10% of energy costs.

The key changes made to the original design of the subdivision in order to incorporate direct gain solar heating included:

- aligning streets east-west so all lots faced south;
- designing each unit so that the main rooms were located on the south side of the house:
- restricting building height to ensure that the shadow of each house falls either on yard space or a street and not on the south wall of other homes;

- where necessary, extending the roof overhangs to shield south-facing windows from the sun in summer while allowing full exposure in winter; and
- slanting roofs at an angle determined to provide maximum efficiency if a homeowner decides to install solar panels for space or water heating.

Solar West, Vancouver, British Columbia

Solar West in Vancouver expects to provide part of residential space heating requirements through direct gain solar heating. The development incorporates the following solar design strategies:

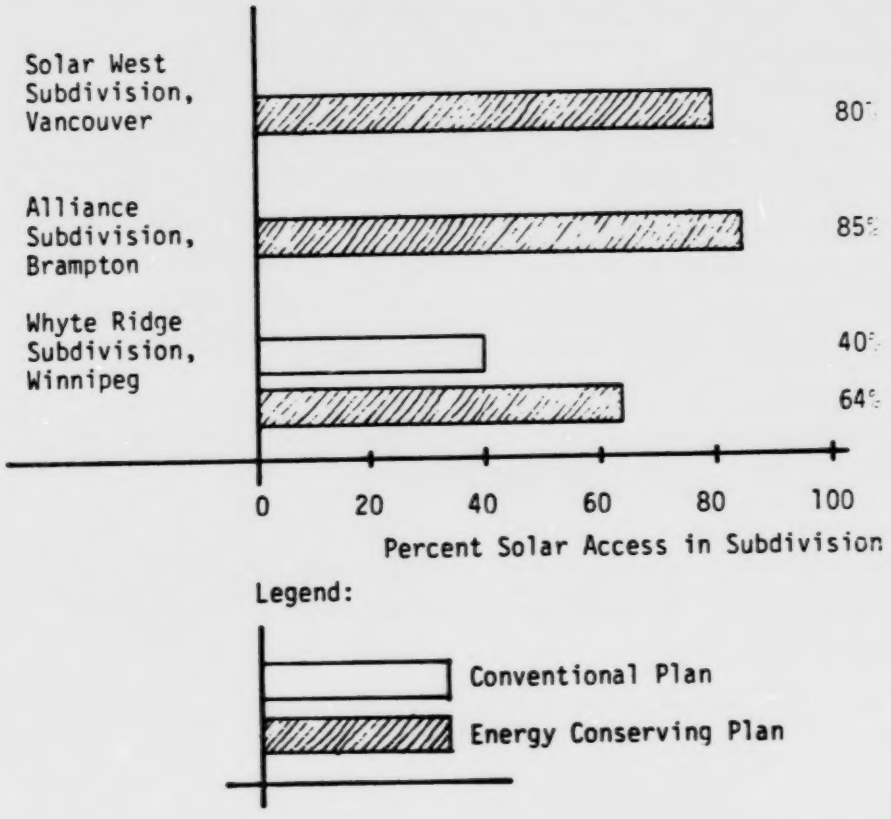
- locating units on south, south-east or south-west facing lots to take advantage of the sun;
- using lower buildings on the south side of streets and in the middle of housing rows to minimize shading of solar skyspace;
- shaping streets to permit solar access to all residences, and
- relating residences to south-facing open space and developing shelter belts and shade plantings.

Streets in Solar West are oriented 15° east of south to take advantage of the sun's heat in winter while avoiding summer overheating.

Tumbler Ridge, British Columbia

In Tumbler Ridge, a resource community in northern British Columbia, there was a major conflict between prevailing winds and solar access: wind buffering as opposed to tree shadowing. Wind was constant, prevailing from the south and southwest at average speeds of 18 km/h. The designers recommended that major clusters of existing trees be preserved, especially along the south and southwest flanks of the town and in several locations interspersed throughout the townsite.

Figure 24: COMPARISON OF SOLAR ACCESS BETWEEN CONVENTIONAL ENERGY-CONSERVING PLANS



Other Examples

Whyte Ridge Residential Subdivision, Winnipeg, Manitoba, on an awkwardly shaped site achieved a 60% increase in solar orientation, from 40% of units within an acceptable solar exposure to 64%. Figures of 85% solar orientation have been achieved in areas such as Alliance Subdivision in Brampton, while Solar West in Vancouver has 80% solar access. These examples assume no loss of yield (Figure 24).

Conclusions

Designing for passive solar requires consideration of the trade-offs in energy costs between all environmental design factors. Solar access regulations should be as flexible as possible to avoid unnecessary development expenditures and lost opportunities for environmental design savings through pursuit of ideal solar access. Flexible lotting and building siting will make up for streets which cannot be oriented east-west due to topography and other site constraints. The following points should be considered in conjunction with the previous environmental design conclusions:

1. Designing for passive solar orientation can contribute 10% to 40% of residential space heating requirements at a cost of 0% to 10% of the cost of residential construction.

2. Direct gain solar access will ideally require windows oriented south or 15° east of south, and unobstructed by shadows between 9:00 hrs. and 15:00 hrs. during the heating season.

3. Flexible solar zoning regulations - based on performance standards -will ensure the best fit between solar access requirements and site conditions. Zoning regulations should encourage east-west or east-north-east to west-south-west

street orientation, lotting on a north-south axis and building siting to orien. windows south or within 22.5 degrees east of south.

4. Where streets cannot be oriented east-west design, approaches which will improve solar access include:

   - angling lot lines
   - combining lots
   - using flag or corridor lots
   - using key or chevron lots
   - regulating building setbacks

5. Solar zoning regulations will also eliminate shading from neighboring structures or trees that could effect the use of direct gain solar heating.

6. The potential improvement in solar orientation between conventional subdivision planning and solar orientation planning ranges from 50% to 100%.

6. NEIGHBOURHOOD ENERGY EVALUATION CHECKLIST

Implementing the full range of neighbourhood energy-conservation principles requires a flexible process of administrative approval. Energy evaluation checklists have been developed in a number of municipalities in order to pinpoint unnecessary embodied or operational energy expenditure in neighbourhood development, and to suggest measures which would increase energy efficiency. Such checklists could become integral parts of the subdivision design process.

The following checklist was developed to summarize the main energy conservation approaches, principles and techniques at the neighbourhood level, and to indicate where energy savings or benefits will occur through their application.

Compact form and mixed land use and environmental design are primary energy conserving approaches. District heating and passive solar have a more restricted applicability. The use of an energy-saving technique in a given situation will depend on relative cost-effectiveness. The effect of energy requirements, opportunities and constraints on energy conservation approaches is indicated at the end of Chapter 2.

THE NEIGHBOURHOOD

ENERGY CONSERVATION CHECKLIST

Approach	Principle	Technique	Potential Savings/Benefits
1. COMPACT FORM AND MIXED LAND USE	a. Locate development close to existing facilities and services	i. choose a site with convenient access to facilities and services; including: public transit, schools, parks, shopping, day care, library, fire protection, arterial roads and major utilities.	- embodied energy for construction of roads and utilities. - operational energy for transportation, operation and maintenance of roads and utilities, and transmission losses.
	b. Mix land uses in the development	i. develop a self-contained neighbourhood with all necessary facilities, commercial, recreational institutional.	- operational energy for transportation
		ii. encourage work in the home ("cottage industry") and employment within the development.	- operational energy for transportation
	c. Increase housing density to between 67 du/ha and 99 du/ha and create a more compact neighbourhood form	i. use higher density housing forms: row-housing, walk-up apartments.	- operational energy for space conditioning - embodied and operational
		ii. create a planned unit development, reduce lot sizes and yard restrictions.	- energy for roads and utilities
		iii. cluster lots for detached homes	

Approach	Principle	Technique	Potential Savings/Benefits
	d. Use efficient and innovative road and utility planning	i. develop an efficient road hierarchy to ensure smooth traffic flow: eliminate 4-way stop signs and use computerized traffic signals, eliminate culs-de-sac.	- operational energy for transporation
		ii. minimize road and utility lengths through innovative planning	- embodied energy for roads and utilities - operational energy for roads and utilities.
		iii. reduce pavement widths and develop neighbourhood parking bays	- embodied energy for roads
		iv. for efficient street lighting use high pressure sodium lamps and space lamp standards further apart if consistent with public safety.	- embodied energy for standards operational energy for lighting.
	e. Encourage alternative modes of transporation	i. provide mass transit in conjunction with higher density and mixed land use	- operational energy for transporation
		ii. develop bicycle paths and sidewalks to provide efficient, non-motorized access to facilities	- operational energy for transportation
2. DISTRICT HEATING	a. Evaluate the viability of district heating versus independent systems	i. use district heating in conjunction with higher density housing (67 du/ha to 99 du/ha) and compact neighbourhood form	- embodied energy due to less transmission line - operational energy in transmission line losses
		ii. use district heating in conjunction with high thermal density (use an energy audit)	- amortization period reduced

Approach	Principle	Technique	Potential Savings/Benefits
	b. Use a flexible system to accommodate community growth and change.	i. use portable plants in new developments until a permanent district heating plant is economical.	- low first costs
		ii. interconnect district heating systems	- energy security
		iii. provide for "District Cooling"	- operational energy for summer cooling
	c. Tailor district heating system to local energy sources and opportunities	i. use alternative low-grade energy sources such as biomass (wood), solar.	- energy security - operational energy
		ii. use in conjunction with cogeneration of electricity using conventional fossil, nuclear or other fuel sources and use waste heat from industrial processes or incineration of garbage.	- energy security - operational energy
3. ENVIRONMENTAL DESIGN	a. Prevent development on hazard lands	i. restrict development on steep slopes	- reduced hazard of slumping
		ii. restrict development on floodplains, bogs and marshes	- reduced hazard of flooding - embodied energy for fill
		iii. restrict development on poor soils for foundations	- embodied energy - reduced structural hazard
	b. Maintain existing landforms, slopes, drainage patterns and vegetation	i. minimize cut and fill by siting building and roads to fit local conditions	- embodied energy - savings in earthwork

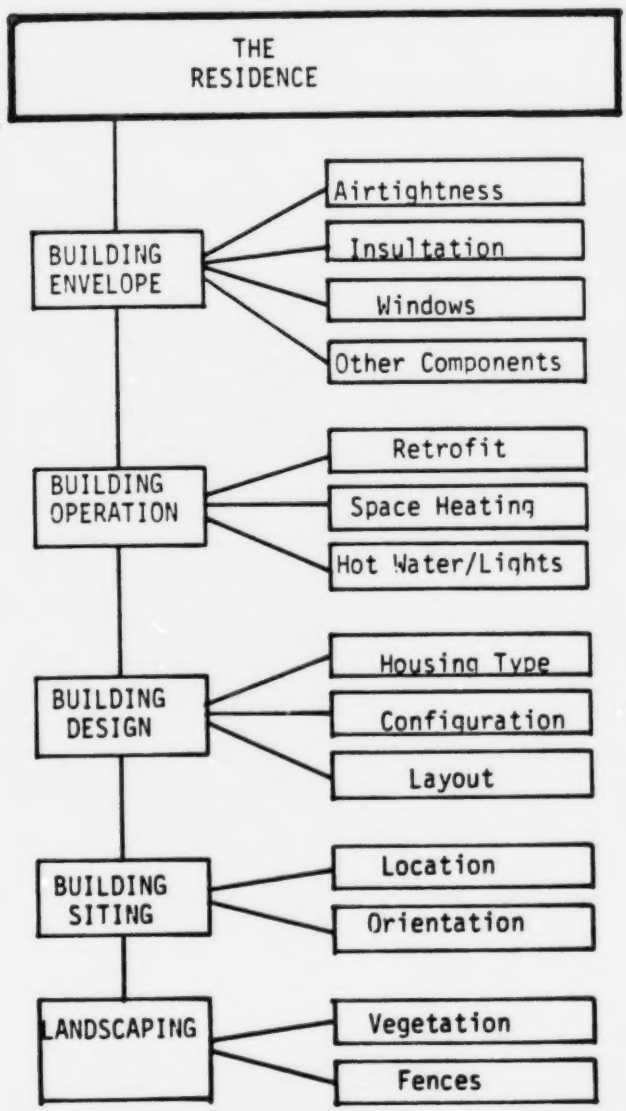
Approach	Principle	Technique	Potential Savings/Benefits
		ii. use open space for natural drainage channels, as well as percolation basins, holding ponds and permeable paved surfaces to reduce site runoff.	- embodied energy - reduced need for site intervention and underground services.
		iii. preserve existing vegetation to modify climate, or as managed wood lots.	- operational energy in space heating and cooling - energy source
	c. Improve local microclimate	i. orient lot and buildings to the sun	- operational energy - solar heating
		ii. provide wind breaks against winter winds such as vegetation, fences, buildings	- operational energy - heating
		iii. channel summer breezes cooling effect	- operational energy - cooling
		iv. impose lot coverage restrictions for unshaded paved surfaces	- operational energy - cooling
		v. use water areas for climate modification	- operational energy summer cooling
		vi. provide a homeowners manual for proper orientation and landscaping	- operational energy heating and cooling
	d. Use energy-efficient, building materials, especially local building materials	i. use natural materials such as earth, stone, wood rather than high energy materials such as steel and plastics.	- embodied energy production of building materials
		ii. use locally available building materials.	- embodied energy transporation of materials.

Approach	Principle	Technique	Potential Savings/Benefits
	e. Minimize neighbourhood maintenance requirements	i. preserve existing landscape	
		ii. use low-maintenance climate adapted plantings	- embodied energy maintenance
		iii. channel winds to keep snow off major streets	- operational energy snow clearing
4. PASSIVE SOLAR	a. Orient major areas of glazing for passive solar gain	i. orient major areas of glazing south or within 22.5° east or west of south	- operational energy space heating
		ii. orient residential streets east-west	
		iii. where (ii) is not feasible use angled lots; combined lots, flag lots, or key lots to ensure solar orientation.	
		iv. where other techniques are not wholly successful stagger building setbacks.	
	b. Use flexible solar zoning regulations to ensure solar access	i. base solar zoning regulations on a performance standard: Major areas of glazing in 75% of all dwelling units should be oriented within 22.5° east or west of south and unobstructed between 9:00 hrs. and 15:00 hrs. during the heating season.	- flexibility of design
		ii. ensure neighbouring structures or trees do not infringe on solar access.	

CHAPTER 5

THE RESIDENCE

Figure 25: THE RESIDENCE LEVEL



1. RESIDENCE LEVEL APPROACHES

The greatest reductions in energy use at the level of the individual house and yard come from minimizing heat loss, and improving or changing heating systems. The potential for residential energy savings will be considered in terms of the following (Figure 25):

- building envelope;
- building operation;
- building design;
- building siting;
- outdoor space planning.

Increasing the airtightness and insulation of the building envelope is an effective way to save energy in housing, but increasing the efficiency of heating systems in combination with improvement of the building envelope may be more effective, especially in retrofitting. Building design, siting and landscaping also produce significant reductions in residential energy use.

Although a multitude of energy conservation measures have been described in the popular literature, their overall costs and benefits are often exaggerated and misleading. Energy audits and lifecycle costing help determine the cost-effectiveness of residential conservation measures. Energy audits determine the energy savings possible if certain conservation measures are applied to particular residence, and relate those savings to total costs. The overall extent to which conservation measures should be applied is determined by lifecycle costing.

Lifecycle Costing

Lifecycle costing evaluates the total cost of a commodity (such as a building), over the assumed life of the project or a given amortization period, considering all operating costs, as well as capital and interest costs. Lifecycle costs may be used to determine the extent to which various conservation measures should be applied to housing, assuming the cost of the conservation measures, the cost of capital (discount rate) and the energy savings are known, and a given amortization period and increase in energy cost is assumed over the life of the project. Fluctuating interest rates and energy costs make accurate lifecycle costing difficult but do not negate the importance of the technique in predicting the cost-effectiveness of energy conservation measures.

If a reasonable lifecycle (amortization period) is projected for a residence and the incremental capital costs for conservation measures are compared to the incremental energy savings projected for that period (assuming an incremental increase in energy costs), the minimum lifecycle cost (capital plus energy) occurs when the incremental savings balance the incremental costs.

Some of the energy conservation techniques presented in this book are evaluated in terms of lifecycle costing using NEP projections for energy costs and an interest rate of 15%; however, in many cases the costs of the conservation measures were not available. The reliability of the projected energy savings in a number of examples is also questionable, since most are based on theoretical studies done before construction and not on actual measurements.

Residential Energy Consumption and Conservation

The operational energy consumed by housing in a typical Canadian city is approximately 35% of total municipal energy use. Approximately 75% of the residential total is used for space heating; 15% for water heating and 10% for lighting and appliances.

2. BUILDING ENVELOPE

New energy-conserving housing saves energy principally by isolating and insulating the indoor living environment from the vagaries of the outdoor climate. The building envelope acts like a thermos bottle to minimize heat loss through conduction, convection and radiation in the heating season, or heat gain in the cooling season; in other words to keep the indoor living environment within the "comfort zone". The building envelope is comprised of the structure, vapour barrier, insulation, cladding, windows and doors which enclose the indoor spaces. Making this as airtight and highly insulated as possible will provide the greatest savings in energy at the level of the individual residence.

Vapour Barrier

Without first sealing all air leakages, the application of other energy conservation measures is ineffectual. Air leakage, or infiltration, in an average dwelling unit is responsible for approximately one-third of the heating load. Therefore, extra care is required in new construction or retrofit to ensure proper installation of the vapour barrier and proper airtightness.

Tightly sealing a house may cause problems related to high humidity and high particulate content in household air. Provision for controlled ventilation is the most effective way to deal with these problems. Air-to-air heat exchangers ensure an adequate supply of fresh air while transferring up to 75% of the heat contained in stale exhaust air to incoming fresh air.

Canada has one of the highest rates of residential energy use in the world. This is not only due to climate, but also to the widespread development of single-family detached housing and the past availability of inexpensive energy. Compared to energy-efficient housing, most existing Canadian homes tend to be drafty, poorly insulated and inefficiently heated. Past wastefulness means Canada now has a large energy conservation resource.

More than 70% of housing units required in Canada to the year 2000 have already been built. To develop their conservation potential, existing residences must be better sealed and insulated, and must be provided with efficient heating systems which minimize the use of expensive, non-renewable fuels.

Particularly in existing residences, energy conservation will require changes in personal habits. Lowering thermostats and wearing warmer clothing indoors, turning off lights, reducing water use, using energy-saving appliances and timers for automobile block heaters, are just some of the ways of reducing household energy use. Reducing the indoor temperature 5°C - from 20° to 15°C will reduce annual space heating requirements in Winnipeg, Manitoba by 14%.

New housing should be built to high standards of airtightness and insulation; have forms related to the climate and micro-climate, and, where possible, use locally available building materials to minimize embodied energy use. Space heating energy should come from local, low-grade sources or alternative sources, rather than using high-grade (refined) fossil fuels or electricity. Low grade energy sources include biomass fuels, waste heat from electrical generation or industrial processes, and solar energy.

Figure 26: SPACE HEATING COST SAVINGS - FRANKEL/LAMBERT INFILL HOUSING, TORONTO

		Space Heating Cost Savings ($ 1981) $	%	Space Heating Fuel Cost per Townhouse per year ($ 1981)
Building Envelope	North-South Baseline			350
	Insulation	66	19	284
	Insulated Shutters	77	22	207
	Total	143	41	207
Building Operation	East-West Baseline			399
	Solar Orientation	49	12	350
	Heat Pump with Solar Storage	59	15	291
	Domestic Hot Water with Solar Storage	57	14	234
	Total	165	41	234

Source: Hix, 1977.

Insulation

Insulation increases the thermal resistance of ceilings, walls and basements. The greater the temperature differential between the desired indoor comfort zone and mean annual outdoor extremes, the greater the required thermal resistance in the building envelope. Insulation requirements vary for different climates; therefore, payback periods may vary. In addition different and insulation materials have different costs and benefits.

Windows

Careful planning of window orientation, type, and size as well as the use of shutters and awnings, can significantly reduce heat losses from windows in the heating season and heat gains in the cooling season. Windows may also provide a net heat gain in the heating season.

Examples

Frankel/Lambert, Toronto, Ontario

The Frankel/Lambert Infill Project (Figure 26) in downtown Toronto compared three and one-half storey stacked townhouse units built to Ontario Building Code (OBC) standards (RSI 2.3 in ceilings and RSI 3.0 in exterior walls) to better insulated but similar units, with RSI 5.3 in ceilings, RSI 4.0 in exterior walls and RSI 1.8 in exterior walls below grade. The higher insulation levels would be cost-effective within a ten year period assuming a 10% interest rate and a 10% escalation in fuel costs.

While OBC units with a north-south orientation had heating bills of $350 ($1981) per year, the better insulated units with the same orientation had heating bills of $284; saving 19% per year due to insulation and reduced furnace size. Generally, sealing against air leakage and increasing insulation levels up to optimum levels are the most effective ways of conserving energy in new residences.

Frankel/Lambert found that units oriented north-south had solar heat gains 45% greater during the winter heating season than those orientated east-west. This extra gain produced savings of 12.5% in energy costs.

Double-glazed windows with insulated shutters were found to be more cost-effective than triple glazing, provided the shutters were kept closed a minimum of twelve hours a night in the heating season. The insulated shutters and double glazing were cost-effective in eight to nine years assuming a 10% annual energy price escalation. Insulated shutters reduced fuel costs 22%, from $350 to $273.

St. Lawrence Neighbourhood, Toronto, Ontario

The ECE Group (1978) projected an 18% decrease in energy consumption in Phase B of the St. Lawrence Neighbourhood in Toronto. This would be achieved through to ensuring the integrity of the vapour barrier in design and construction and controlling air leakage; through increasing insulation values to those recommended in Measures for Energy Conservation in New Buildings (1978) and through orienting units so that more windows faced south.

The use of triple glazing was not recommended. While double-glazing could be ammortized in under ten years, assuming a 10% annual energy price escalation, triple glazing would require sixteen years.

The St. Lawrence Neighbourhood researchers found that the payback period for insulated shutters would also be sixteen years. This lengthy payback period takes into account shutter hardware such as frames and locks, as well as the cost of visually relating the shutters to the building.

Energy Showcase, Saskatoon, Saskatchewan

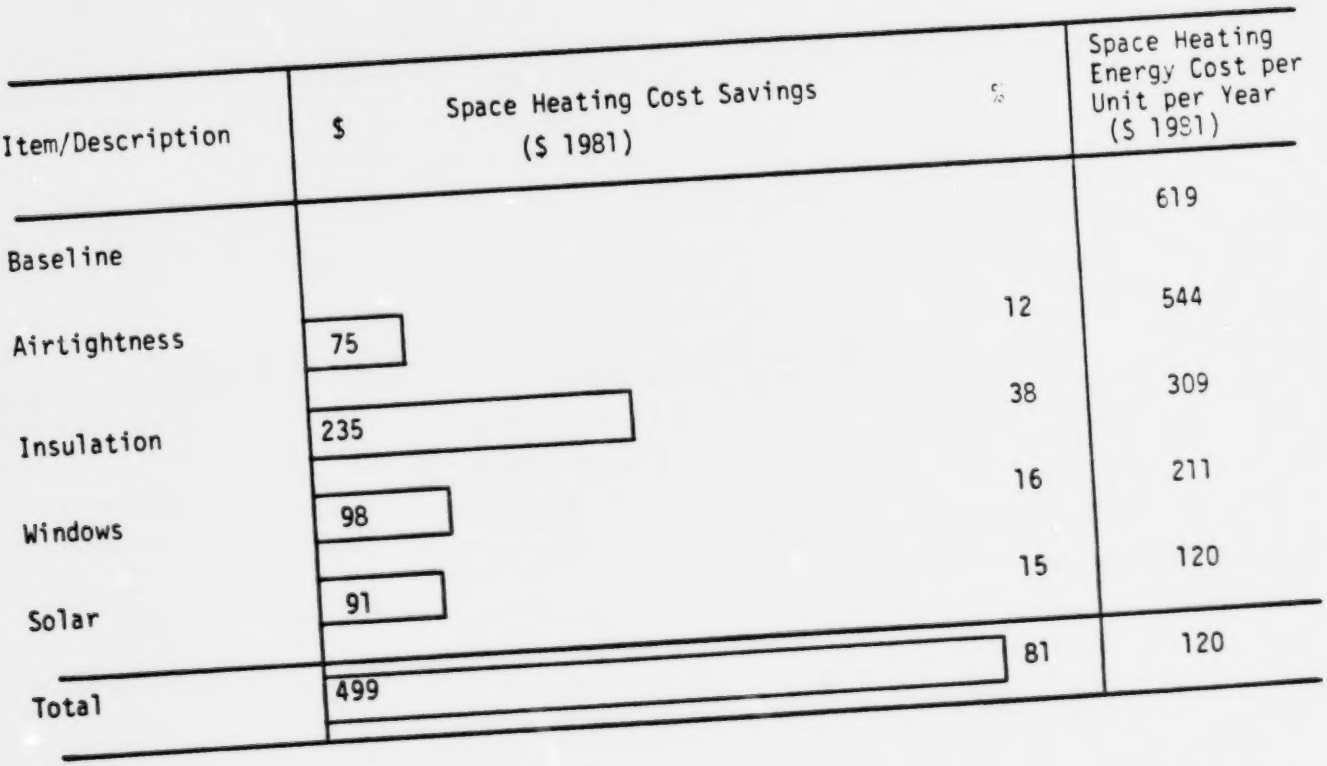
The conserver homes in Saskatoon's Energy Showcase included a variety of insulation levels with double-wall, single wall and strapped-wall systems. Some of the conserver homes have super-insulated 38 mm x 140 mm stud walls, impermeable membrane air barriers, triple pane windows and air-to-air heat exchangers. Insulation is RSI 8.8 to 10.6 in ceilings, RSI 6.0 to 7.0 in exterior walls and RSI 3.9 to 7.0 in basement walls.

The cost differential between these 102.2 m^2 low-energy houses and similar-sized conventional houses was only $2000 to $4000 per unit. The conventional houses used fiberglass insulation in 38 mm x 89 mm stud walls, 51 um polyethylene vapour barriers and double glazing on all windows.

The National Research Council estimated this modest investment for energy-saving features would save 50% to 90% of the energy needed for space heating the conventional houses. Assuming the homeowner paid $3000 extra for the energy-saving features of the superinsulated house and assuming fuel price increases cancelled interest on that investment, energy savings would total $525 annually for electrically-heated low-energy residences and $500 for oil heated low-energy houses - both six-year payback periods. The payback period for natural gas, at savings of $200 per year, would be fifteen years.

Evaluation of the actual performance of the Saskatoon Energy Showcase homes indicates that the maximum energy savings are about 60%, however - much less than initially anticipated. This lower performance, coupled with high interest rates, means the energy-saving homes are not cost-effective within a ten year payback period.

Figure 27: SPACE HEATING COST SAVINGS - SOLAR WEST, VANCOUVER, B.C. (Semi-attached housing; electric heat)



Source: Moodie et al, 1979.

Solar West, Vancouver, B.C.

Solar West in Vancouver (Figure 27) achieved a 64% overall reduction in energy use for space heating, water heating, appliances and lighting, and an 81% reduction in space heating energy alone.

Solar West was to have been a solar demonstration community relying on both passive and active solar systems for space and water heating, but this conflicted with the development objective of achieving energy-efficient housing without subsidies. Active solar systems would have increased the cost of each housing unit as much as $10,000 - an amount few homebuyers would be willing to pay. Passive solar systems would have demanded major lifestyle changes - also considered unacceptable in the marketplace. The solar approach was therefore de-emphasized in favour of more traditional energy saving features. These add about $4,000 to unit construction costs (3% to 5% of the cost of a unit) and are expected to have a 5 to 10 year payback period.

- The key energy conserving measures include:

    - careful caulking and weatherstripping;
    - insulation levels of RSI 6.7 in ceilings and RSI 3.5 in exterior walls, and concrete slab foundations insulated to a depth of 457 mm;
    - double-glazed windows;
    - forced-air gas furnaces with electronic spark ignition a and continuous fan and flu dampers;
    - outside air fireplaces with heat exchangers;
    - front and back door airlock entries, and .
    - family living areas generally on the south sides of units with large south-facing windows protected by eaves for summer shading bedrooms; utility rooms, closets and bathrooms generally on the north side with small north-facing windows.

The project is being monitored by the Champlain Heights Development Group with particular attention to problems of moisture build-up in airtight houses.

3. BUILDING OPERATION

The heating or cooling requirements of a building depend on its heat loss characteristics, the micro-climate, and the amount of heat obtained from people, appliances, lighting and solar gain. The cost of heating or cooling a building is directly related to the availability and cost of the energy source and the cost and efficiency of the mechanical heating or cooling devices used. In the Canadian climate space heating is generally of greater concern than space cooling.

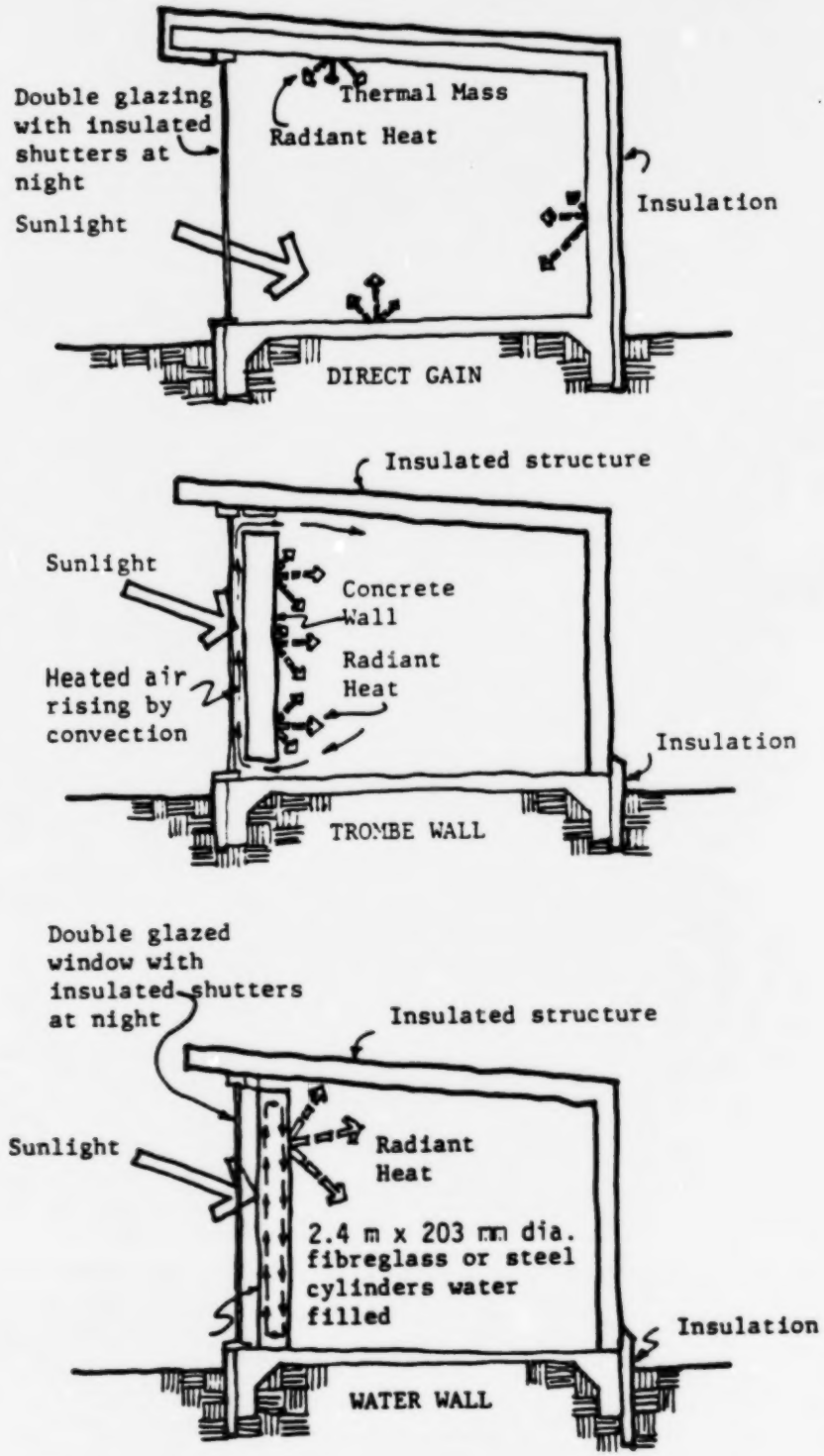
While the prices of electricity and natural gas differ considerably between regions, the price of home heating oil-as perceived by consumers -is relatively uniform, due to federal oil-pricing policy. Opportunities for alternative energy use vary between energy zones. (See Energy Zone Map).

Retrofit

In existing residences, where substantially modifying the building envelope is expensive and often impractical, and where use of passive solar and other alternative energy sources is constrained, the best alternative is to convert to the most economical form of energy available and to use the most efficient heating devices to convert the energy source to heat.

The cost-benefits of the Saskatchewan Conservahome Program of energy retrofit emphasize the importance of building envelope and heating systems in retrofit. However, the cost-effectiveness of this program is generally not comparable to that of new energy-efficient

Figure 28: PASSIVE SOLAR SYSTEMS



Source: Moodie et al, 1979.

homes. The amortization periods range from approximately 10 to 90 years depending on the characteristics of the existing houses Some increments of retrofit may be cost-effective even where the whole package is not.

To ensure that retrofit is cost-effective (has an acceptable amortization period) requires a residential energy audit. This is a thorough review of existing energy use and heat loss by a qualified individual or team. The procedure is essential in establishing implementation priorities for energy conservation strategies. A residential energy audit collects data on the airtightness, insulation, operational heating efficiency and energy expenditures of a residence and enters them on performance forms. These facts then allow a calculation of potential savings versus costs, facilitating decision making by homeowners.

Residential Solar Systems

Passive solar heating with a back-up system, or in conjunction with a thermal storage system, is an alternative to conventional energy systems. Passive solar heating requires south-oriented windows which catch the sun during the heating season and are shaded during the cooling season. The use of solar energy has an impact on the design and operation of housing, as well as their siting.

Passive solar space heating systems (Figure 28) should only be considered after all economic optimum energy conservation measures have been taken. The contribution that solar energy can make to the reduction of fossil fuel use varies from 10% to 40%. The law of diminishing returns tends to mitigate against solar systems with very large (40% and above) solar heating contributions - the cost of capturing the additional energy becomes uneconomical.

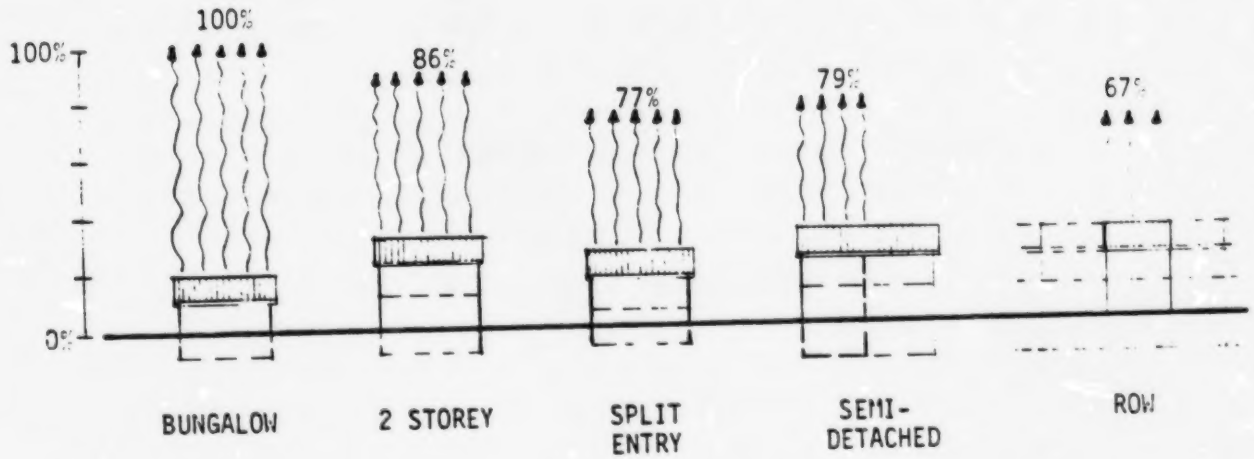
The current cost of a direct gain passive system is in the order of 0 to 10% (0 to $6,000) of the cost of construction of the housing unit. Other passive solar systems such as Trombe walls and water walls will run 5 to 12% ($3,000 to $7,200) of the cost of the housing unit. Direct gain systems work most effectively when double-glazing is combined with night-time insulated shutters and additional thermal mass is incorporated with the building structure. Trombe and water wall systems require the construction of south-facing mass walls or water containment systems behind glazing.

The Saskatoon Energy Showcase housing incorporated a number of passive solar systems, including Trombe walls, solariums, green-houses and various window arrangements. Beadwall windows and a number of other window insulation devices, such as shutters were used to prevent heat loss.

Active solar systems are less practical for space heating in Canadian climates. They can cost from $8,000 to $10,000 and up, and payback periods range from 20 to 50 years, or longer at present energy prices. Since the relationship between the cost of the solar heating device and the type of building on which the device is to be fitted is slight, multiple-family buildings with ten to twelve low-rise units may be the most economical application of active solar systems.

Between 15% and 20% of the energy used in conventional residences goes toward domestic water heating. Solar domestic hot water systems are more cost-effective in small buildings than active solar space-heating systems. The proportion of useful heat they deliver is greater because any increase in the temperature of inlet water to the collector will ease the load on the conventional domestic hot water system throughout the year. Flat plate solar panels costing approximately $3,000 can provide 50% to 75% of an average family's hot water requirement for a year. Since the average family spends $100.00 to $200.00 per year on hot water, the payback period for such a system would be 15 to 30 years.

Figure 29: RELATIVE HEAT LOSS BY BUILDING TYPE



Note: Heat losses are shown as a percent of heat loss of the bungalow of same habitable floor area.

Source: Ontario Ministry of Energy, 1980.

4. BUILDING DESIGN

Building type, configuration and layout considerations have a moderate impact on energy conservation.

Building Type

A row-house unit attached on both sides will save 33% of the energy used in a single-family detached bungalow of the same habitable floor area (Figure 29). Stacked townhouse units and walk-up apartments are even more energy efficient, saving up to 40% of the energy used in a bungalow. This is a result of the much decreased exterior surface area to volume ratio in the townhousing or apartment unit.

While energy conservation considerations favour higher density building types, such as stacked town housing; (approximately 67 du/ha) the Canadian housing market is still primarily a market for single-family detached residences (approximately 12 du/ha)

On the other hand, consideration of housing configuration and layout is important to single family housing especially in reinforcing other energy conserving features.

Building Configuration

Heating requirements are reduced by using compact building configurations which are responsive to local climate, and the site. Housing units with compact forms have the least exposed surface area to volume ratios - minimizing the area for conduction and radiation heat losses. While a hemispherical dome has the least possible surface to volume ratio, the practicality of building curvilinear forms using conventional building methods is low. If conventional construction methods are used, a cube provides the minimum surface area to volume ratio. Two-storey houses with nearly square plans have been shown to save 14% of the energy

required for single-storey rectilinear plans with the same habitable floor area. Sinking the cube partially below ground, as in split-level dwellings, will produce further savings Wholly underground houses with sun-trap courtyards are more practical in dry climates without snow than they are in the majority of Canadian situations.

Internal Layout

The layout of interior spaces also affects residential energy conservation. Locating active living spaces, such as living rooms, dining rooms and kitchens, on the south side of the house where they can catch the sun, will reduce energy requirements for both lighting and heating. Bedrooms, storage, and utility spaces create a buffer zone on the cool north side of the house. Attached or separate garages will buffer main living areas from cold winter winds. An air-lock entry or heated vestibule will also help minimize heat losses.

The magnitude of savings derived from careful layout of interior spaces, or consideration of building configuration, is not available. Building form and layout must be responsive to building location, and building orientation for wind buffering and passive solar-energy collection.

5. BUILDING SITING

Properly locating and orienting a residence to consider winter wind buffering, summer cooling, solar gain and solar shading will reduce energy use. The magnitude of such savings is a matter of debate.

The location of single-family housing should maximize solar access, minimize exposure to cold winter winds and channel cooling summer breezes. Larger, multiple-family structures, on the other hand, may be used to buffer cold winds and may also be located in less favourable areas for solar orientation.

Figure 30: LOT ORIENTATION CRITERIA

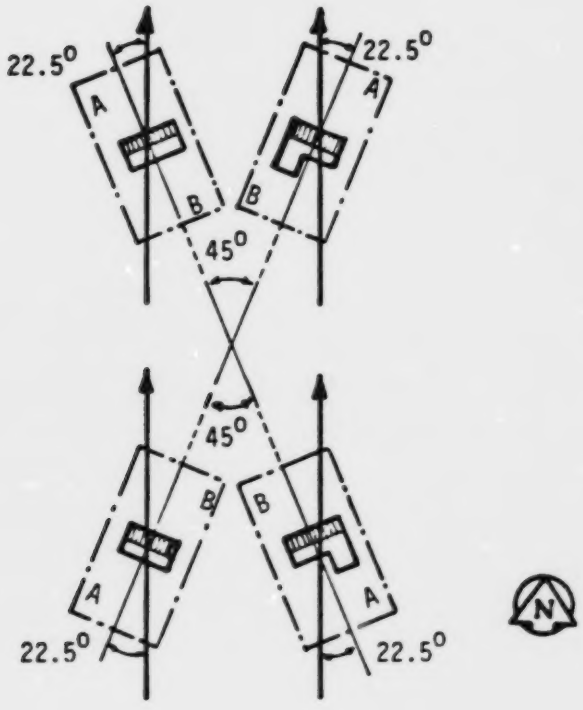
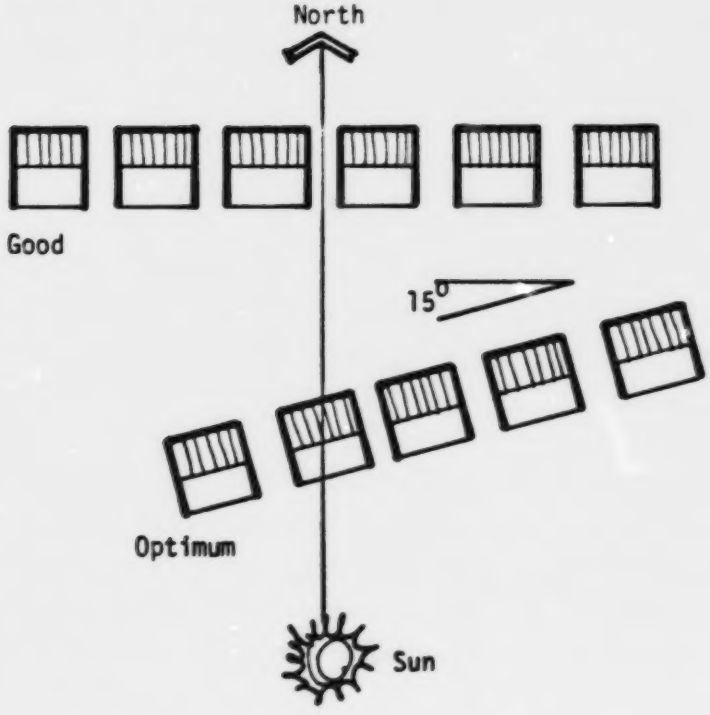


Figure 31: SOLAR ORIENTATION OF A HOUSE



Where possible the orientation of a residence should maximize solar access; single-family detached housing should be oriented so the longest side and largest roof area will receive the maximum solar radiation from the south.

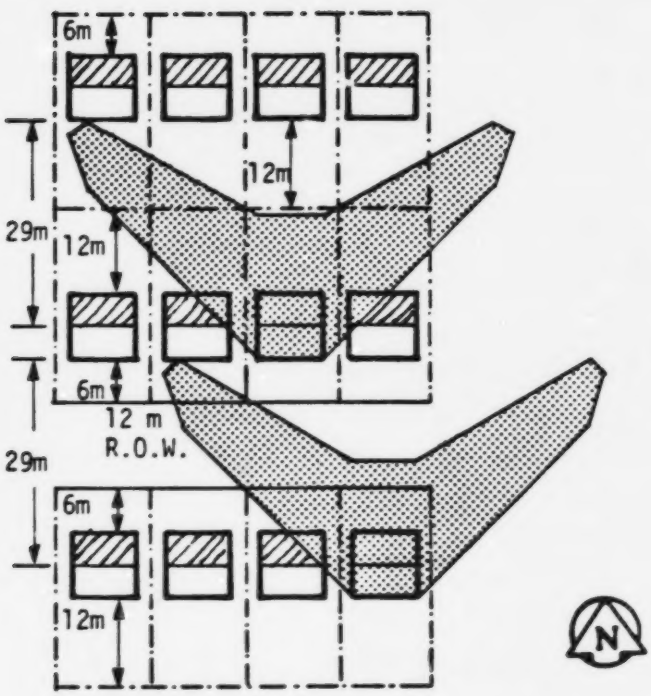
The ideal orientation for solar access may vary slightly depending on the regional location of the house. Generally 15° east of south is an excellent orientation, providing maximum solar heat gain early in the day during the winter months and minimizing heat build-up in the summer (Figure 30) . Any orientation which allows the largest surfaces of the house to be oriented to the south, as opposed to east or west, is still optimum.

Orientation of a residence in a north-south direction may be difficult on some sites or lots. Street layout, lot shape and building setbacks affect the orientation of a residence. If streets are not oriented east-west, lots will not easily be oriented north-south. If streets lie along a north-west, south-east axis or vice versa, both lot lines and building setbacks must differ from traditional forms in order to maximize solar access. Lot lines may be changed from perpendicular to different angles, and standard building setbacks waived (Figure 31).

Before waiving traditional setbacks the sunshadows of buildings should be checked to ensure that they will not shade the adjacent buildings' skyspace. A simple check is to draw the 45° solar azimuth lines (Chapter 4, Section 4) to see if these lines strike any adjacent buildings. This is especially important in the case of residences located on intercardinal streets.

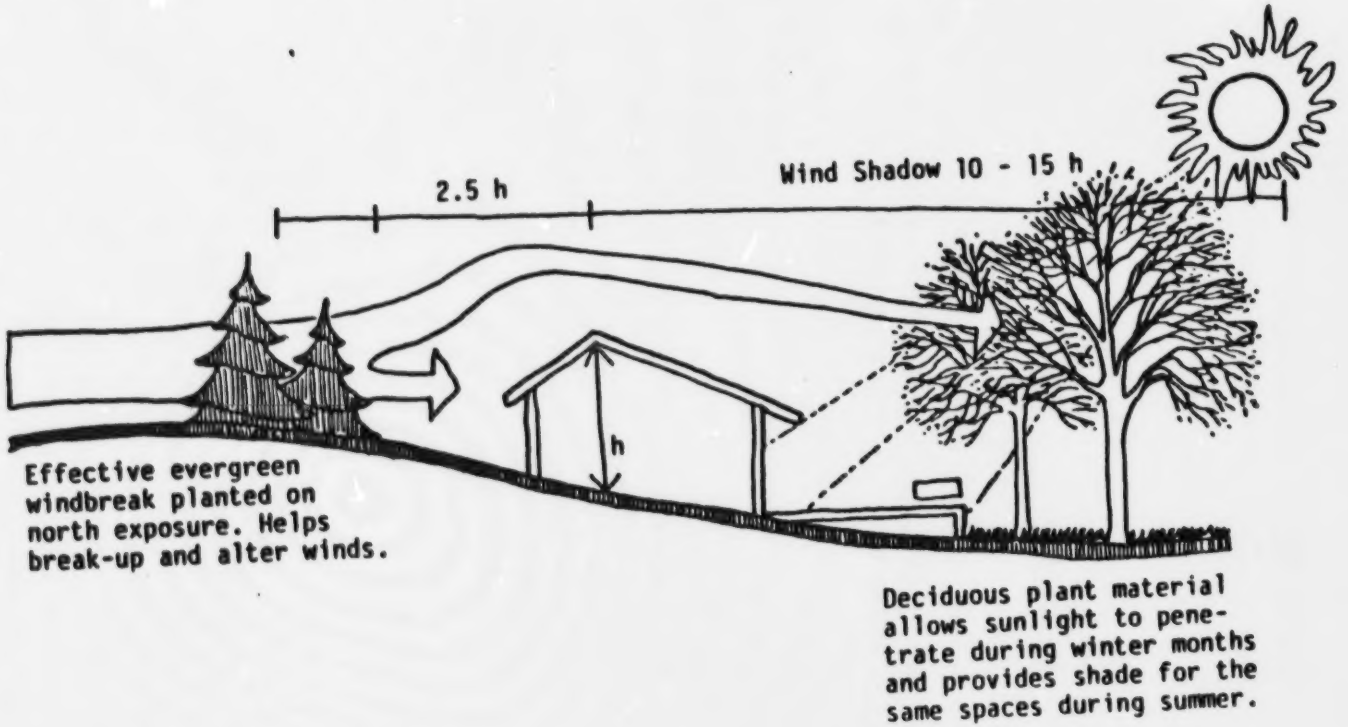
Where streets run north-south, lots and buildings are generally oriented east and west: this makes solar access difficult. Regularly staggering building setbacks will give residences solar exposure for part of the day. Although energy savings related to this technique have not been researched, some of the benefit of solar access may be gained even with severe site constraints, such as easterly sloping topography.

Figure 32: REDUCING SETBACK TO EQUALIZE ACCESS



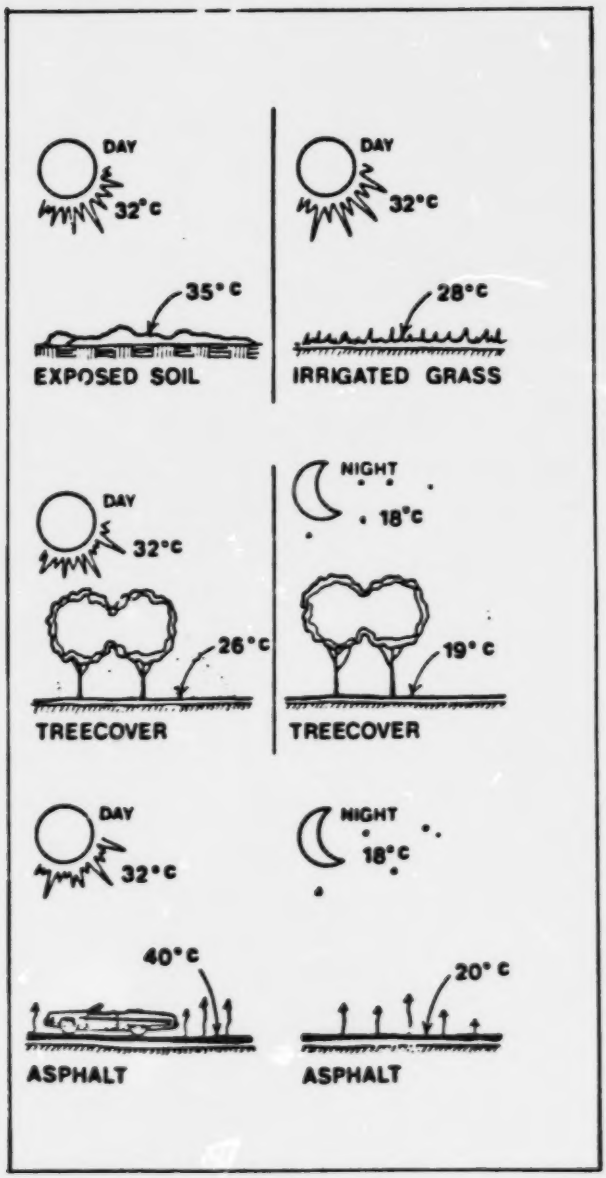
NOTE: For hypothetical site, flat at 48° N latitude, with a shadow protection for 3.5 m high buildings.

Figure 33: SAVING ENERGY BY WAY OF SITE DESIGN


2.5 h
Wind Shadow 10 - 15 h
h
Effective evergreen windbreak planted on north exposure. Helps break-up and alter winds.
Deciduous plant material allows sunlight to penetrate during winter months and provides shade for the same spaces during summer.

Source: American Society of Landscape Architects. 1977.

FIGURE 34: TEMPERATURES



Source: American Society of Landscape Architects, 1977.

Building setbacks (Figure 32) are also important on conventional lots oriented north and south. If south entry units do not have regular front yard setbacks and north-entry houses do not have uniform rear yard setbacks then certain houses will lose part of their solar access.

6. LANDSCAPING

The use of trees, ground cover, landforms, water, fencing and auxillary buildings can protect a residence both from winter heat loss and summer over-heating. However, planting trees, shrubs and grass and developing other landscaping for energy conservation purposes is not cost-effective. If landscaping is done for other reasons, such as aesthetics, then the location, type and quantity of vegetation should consider energy conservation.

Vegetation

Landscaping for energy conservation can involve the use of land forms, vegetation, fences and structures. The correct type, quantity and locations of vegetation can protect a building from overheating in summer and heat loss in winter. Landforms, trees and shrubs must be planned so that a house will receive maximum winter wind protection and solar access, will be protected from the summer sun and receive the benefits of cooling breezes. If a house is not protected, wind infiltration will create additional heating requirements in winter and excessive solar gain will create additional cooling requirements in summer.

A dense pine, reducing wind speed 85% for a distance of 12 meters leeward, will decrease air infiltration by 40% (Figure 33). Vegetation can also be used to reduce temperature. Air temperature and radiation are about equal in their effect on human comfort. On a hot day grass would have a surface temperature 6% to 8% lower than the air temperature yet a street or concrete patio would have a surface temperature 25% higher (Figure 34).

By reducing the winds' velocity through frictional drag, a fence can reduce the air infiltration into a house. The cost of constructing a fence for the sole purpose of reducing air infiltration is, again, not economical. Similarly, auxiliary buildings can be used to divert airflow and/or provide shade. Their location, however, must be carefully planned to maximize the energy savings and to prevent solar shading during the heating season.

7. RESIDENTIAL "KIT OF PARTS"

Improvements in the building envelope of existing houses, other than weatherstripping and caulking, should be based on a comprehensive energy audit to ensure their cost effectiveness. Replacing old furnaces with more efficient heating devices should also be based on the results of an energy audit and should consider the lifecycle of existing equipment and the proposed new equipment.

Energy conservation choices in new residences will greatly depend on the design of new neighbourhoods. Neighbourhood density and compactness will influence residential building type and configuration. District heating, passive solar design and wind buffering at the neighbourhood level will affect the thermal requirements, design and siting of new residences, as well as the landscaping of private outdoor space. Heating systems should not be overdesigned or costs will exceed benefits. Building design and siting should consider neighbourhood microclimate: solar and wind exposure; shading and buffering, and general temperature and precipitation. Space heating and cooling, and water heating requirements in residences should utilize the most efficient energy sources available.

Residential landscaping may be integrated with an overall neighbourhood concept for energy conservation. Landscape conservation principles can be applied to both existing and new residences.

The following techniques are a "Kit-of-parts" for residential energy savings. Not all "parts" apply to every situation: the energy savings associated with different techniques may vary considerably, depending on the interrelationship of many variables.

Building Envelope

1. Residences should be made as airtight as possible through the careful installation of air barriers, caulking and weatherstripping. Up to 33% of the residential heating load may be reduced in this way.

2. Tightly sealed residences should use air-to-air heat exchangers to ensure a fresh air supply and control excess condensation.

3. Residences may reduce space heating energy requirements from 15% to 75% through increasing insulation levels in conjunction with airtightness. Insulation requirements will vary between energy zones and depending on the heating system to be used.

4. Windows should be oriented away from prevailing winter winds and toward the winter sun, with proper summer shading. This normally implies minimizing north-facing glazing and maximizing south facing glazing. In addition, orientations which are hard to protect from excessive summer heat gain should be avoided, such as east and west. Proper window orientation can save 10% to 40% of space heating energy requirements.

5. The economics of glazing - single, double or triple - will vary from one project to another; however, double-glazing on the south side and triple glazing on the north side of a residence seems to be economical in most parts of southern Canada.

Building Operation

6. Retrofit should be based on an energy audit.

7. Space heating should use the most efficient and least expensive available energy system. This will vary depending on the energy sources available in a given area.

8. Where natural gas is available, heating efficiencies may be increased by 25% to 50% using new technologies.

9. Use of "add-on" hybrid systems - oil furnaces and heat pumps, for example - will save energy and cost in retrofit situations or where oil is the least expensive fuel.

10. Passive solar systems should only be used where system costs are amortized in less than ten years. This will be affected by a number of factors including neighbourhood design and the thermal efficiency of the residence. Solar heating can supply 10% to 40% of space heating needs.

11. Measures to save energy in heating water can save up to 15% of total residential demand.

12. Increasing lighting efficiency can save electrical energy requirements - the magnitude will depend on latitude and building siting and orientation.

Building Design, Building Siting and Landscaping

13. Higher density building types will save up to 40% of the energy required in a single-family detached house. Row housing saves 33% of the space heating energy used in a detached bungalow, semi-detached housing saves 21%.

14. Building configuration also affects heat loss. Two storey houses with nearly square plans will save 14% of the energy required for single-storey rectilinear plans. Split levels will save 23% of the space heating required for similar sized bungalows.

15. Buildings designed to channel cold winds over or around the structure will save energy.

16. Residences designed to use "cool" internal spaces, such as storage areas and bedrooms, as buffers on their windward sides, while taking advantage of the sun in living spaces such as family rooms, living rooms and dining rooms, will save energy. Use of air lock entries will also save energy.

17. Residences should be located to minimize exposure to cold, winter winds and maximize exposure to winter sun. Generally, orientations of up to 22.5% east or west of south will provide substantial opportunities for solar heat gain. Residential orientation is often dependent on the neighbourhood layout of streets and lots.

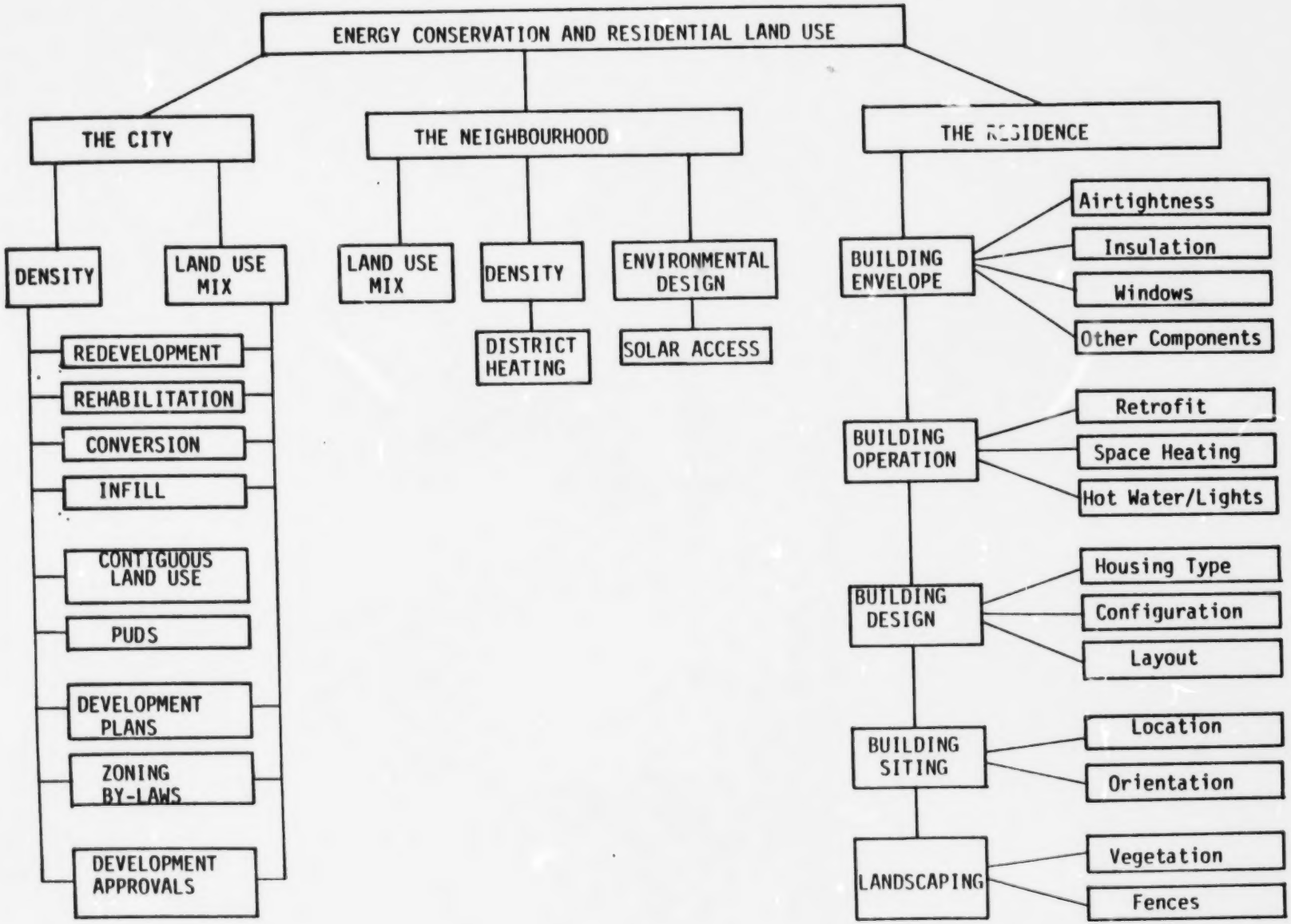
18. Residential setbacks should be coordinated within a development to maximize the potential for solar heat gain in winter. This implies fairly uniform setbacks to protect a 45° solar azimuth line on lots oriented north to south and a varied set-back to catch the sun for part of the day on lots oriented east to west.

19. Land forms, trees, fences and auxiliary buildings should be organized to minimize residence exposure to cold winter winds and hot summer sun while not interfering with solar access. These landscape elements may also be used to channel cooling summer breezes.

CHAPTER 6

CONCLUSION

Figure 35: MAJOR CONSERVATION APPROACHES



This overview of energy conservation and residential land use has focused on the costs and benefits of energy conservation at the level of the city, neighbourhood and residence. A number of approaches have been put into perspective and their potential energy savings highlighted (Figure 35).

While recognizing that energy conservation is of national importance and part of the federal government's strategy to achieve energy security; economic benefits will remain the primary incentive for government, private industry and individuals to conserve energy. Those conservation approaches which provide the greatest savings with the least costs should be pursued first.

Despite future variability in energy prices and inflation, the long-term rise in energy prices is assumed to be at rates of 2% above inflation for electricity and natural gas and 4% above inflation for heating oil. This will change the whole picture of conservation costs and benefits, making the use of lifecycle costing essential for projecting the cost-effectiveness of any conservation measure. In some cases conservation measures will be undertaken now, even if they are not cost-effective in simple payback terms, in order to save energy in the future.

The three levels of residential land use - the city, the neighbourhood and the residence - have served to separate the principal conservation issues into manageable groupings, each with a major point of focus. The city level and the neighbourhood level dealt with the organization of land uses to produce energy savings, primarily through reductions in embodied energy requirements for roads and utilities, and reductions in operational energy requirements for transportation. The neighbourhood level also considered the use of environmental design to save embodied energy and operational energy for space heating and cooling, and the use of

district heating and passive solar to reduce conventional energy use. Finally, the residence level considered improvements to the building envelope, operation, design, siting and landscaping to reduce space heating and cooling energy requirements.

These sets of principles are interrelated. Which are most applicable to a given situation depends on factors such as marketability and development regulations as well as the energy requirements and opportunities of the relevant energy zone. Developers and planners will likely pre-select those conservation principles which fit the development context, applying techniques which are most suitable to the local context and most interrelated.

The major interrelationships between the city, neighbourhood and residence levels are:

- density and district heating;
- density and building design;
- district heating and building envelope;
- district heating and building operations;
- environmental design and building design;
- environmental design and building siting;
- environmental design and building landscaping;
- environmental design and passive solar;
- passive solar and building envelope;
- passive solar and building design;
- passive solar and building siting; and
- passive solar and building landscaping.

Many interventions to conserve energy will require massive and concerted efforts by both public and private sectors. Most require significant changes in lifestyle; for example, giving up the single-family detached house with a private yard in favour of higher density accommodation, and using public transit instead of the private automobile. Or they may require significant changes

in conventional approaches; for example, developing performance standards for solar access in subdivisions or developing construction practices which ensure adequate insulation and proper air barrier installation.

While not all providing the same magnitude of savings, measures from among the following sets of actions will likely produce the best balance of costs and benefits in existing and future areas in various Canadian environments:

Existing Areas

1. Encourage development in existing areas through development plans, zoning by-laws and incentives;
2. Develop attractive and energy-efficient public transportation systems.
3. Increase densities to the optimum level of about 67 du/ha wherever possible through encouraging higher density redevelopment, rehabilitation, conversion and infill;
4. Mix land uses through similar strategies and zoning by-laws which encourage cottage industry, local commercial and transit oriented development;
5. Develop district heating systems in conjunction with garbage incineration and cogeneration of electricity in areas where population size and density make such systems viable;
6. Retrofit existing housing based on energy audits to determine the principal areas and optimum levels of expenditure on energy conservation. Retrofit will likely concentrate on improving the airtightness, insulation and the efficiency of heating and cooling devices in a residence.

New Development

1. Ensure development is contiguous with existing built up areas and located to minimize the capital costs of transportation and utility infrastructure and to minimize the location of urban development on good capability land for agriculture,
   forestry or other resource use.
2. Develop higher densities and mixed land uses to create pedestrian, bicycle and public transit oriented developments;
3. Use district heating if economically viable;
4. Apply environmental design principles to ensure that the development is taking the best advantage of site opportunities and minimizing the effects of site constraints;
5. Ensure that a maximum number of units are oriented for solar access through the proper alignment of streets, lots and buildings for solar access;
6. Develop conserver houses with optimum levels of insulation, airtightness, and window glazing; oriented to take advantage of the sun's energy;
7. Use higher density, compact housing forms with internal layouts responsive to the external environment;
8. Use optimum combinations of heating systems and thermal efficiency.
9. Where developing landscaping as an amenity, plan for energy conservation.

If the standards of energy efficiency, considering local energy zone variables (characterized by existing low energy homes in Vancouver and Saskatoon) were applied to all future residences in Canada, significant reductions in the overall amount of energy used in this country could be achieved. The problem is to convince home buyers to spend the extra increments for conservation and to convince developers and home builders that they will do so. There is a need to encourage cost-effective energy conservation in new housing but also significant levels of retrofit which, could will save large quantities of conventional fuels and move Canada closer to energy self-sufficiency.

This country has a wide range of energy opportunities, both conventional and alternative. Energy conservation is the cornerstone for the reduction of immediate energy requirements giving Canada time to develop new energy sources.

GLOSSARY

Active Solar System. A heating or cooling system that requires mechanical devices to move the collected solar energy.

Alternative Energy Sources. Energy sources which are renewable, such as solar, wind, biomass, geothermal and tidal, or almost inexhaustible, such as nuclear fusion. This term is used to differentiate those energy technologies which are not yet in general urban residential use from conventional technologies related to fossil fuels, hydro power and nuclear fission.

Berm. A man-made mound of earth; important both as a freestanding, wind-sheltering technique and, when placed adjacent to buildings, as a means of increasing thermal resistance.

Biomass. Any organic matter which is available on a renewable basis, including agricultural crops and agricultural waste and residues, wood and wood waste residues, animal waste, municipal wastes, and aquatic plants; usually used in the context of the type of fuel for community central heating plant systems.

Cogeneration. The production of thermal energy and electricity in combination, whereby the waste energy from producing electricity, which is usually vented into the atmosphere or cooling water is recovered and used. Frequent uses of the recovered heat include space heating and water heating which in turn can be used to produce air conditioning or to improve wastewater treatment efficiency. Cogeneration provides a higher overall cycle efficiency than generation of electricity and heat separately since the same energy source is used to provide more than one service.

Conventional Energy Sources. Energy sources which are generally used for residential space heating, water heating, lighting and appliances including fossil fuels such as natural gas, oil and coal; hydro-electricity, and nuclear power and heat.

Cost-Effective. Measures which are cost-effective have short payback periods or a good benefit to cost ratio.

Degree Day. A measurement of the relative severity of an area's heating or cooling season; a degree day is equal to each one degree Celsius deviation from the reference point of 18° C in the mean daily outdoor temperature. Thus a mean daily outdoor temperature of 10° C represents 8 heating degree days, while a mean daily outdoor temperature of 23°C represents 5 cooling degree days.

Design Temperature. A temperature representing the lowest expected for a location and used in determining the design heating load (the total heat loss from a building during the most severe winter conditions likely to occur).

District Heating. A heating system that distributes a heating fluid, usually steam or hot water, through pipes to individual buildings from a central plant. Some district heating systems contain cogeneration aspects of waste heat recovery from electricity production, incineration, and industrial processing. District heating is widely used in the Scandanavian countries. There are also district cooling systems.

Double-glazed. A sandwich of two separated layers of glass or plastic enclosing air to create an insulating barrier in windows, skylights, greenhouses, and solar collector coverings.

Embodied Energy. The amount of energy expended to manufacture and put building and infrastructure materials (and systems) in place.

Energy Audit. An energy audit is a means of determining how efficiently energy is being used. In a residence this means a thorough review of building energy use and heat loss, which will permit the owner to make decisions about the most cost-effective means of reducing energy use. In a city, this means a review of overall energy use, including embodied and operational energy, to determine where savings are possible.

Heating Season. The period in which additional heat is required in a residence to ensure personal comfort. The winter heating season in Canada ranges from moderately short on the West Coast of British Columbia and in Southern Ontario, to very long in the Arctic. Heating degree days provide an indication of the length and severity of the heating season.

Heat Pump. A space conditioning unit that cools like a conventional air conditioner or refrigerator by removing heat from the inside air and delivering it to outside air but that, in reverse, heats by removing heat from outside air and delivering it to the interior. Air-source heat pumps are most common but heat pumps can also exchange energy with a water body. Although gas-fired heat pumps are commercially available, heat pumps are usually powered by electricity. Electric heat pumps are an efficient use of electricity since it is possible to obtain 2 to 3 times the heat output for the same electric input as in conventional electrical resistance heating. Heat pumps also can be solar-assisted.

Infiltration. The uncontrolled air leakage into or out of a building, usually expressed as the number of air changes per hour of an air volume equal to the interior space.

Insulation. A material or system that is used to retard heat loss or gain.

Joule. A unit of energy use equal to a newton-m/sec^2.

Langley. A unit of solar radiation equivalent to one gram calorie per square centimeter of solar illuminated surface.

Life-Cycle Cost. A measure of total system cost over its expected lifespan to include initial production (or construction), maintenance and repair, and operating costs (such as energy consumption). The accumulation of costs over the system's life is usually presented in terms that reflect the relative value of money over time (discounting future costs to present value).

Low-Energy Housing. Housing with very low levels of energy use due to high levels of airtightness and insulation, and careful consideration of all factors related to heat loss and power wastage.

Mb/d. Million barrels of oil per day or the primary energy equivalent.

Operational Energy. The amount of energy expended in space heating and cooling, lighting, running appliances, transportation and operating and maintaining services.

OPEC. Organization of Petroleum Exporting Countries.

Passive Solar System. A heating or cooling system that requires no mechanical devices to capture, store and utilize collected solar energy.

Payback. A measure of economic viability of a project or system; usually defined as the number of years required to accumulate savings which exactly equal the initial capital cost of the system. Payback does not give an accurate portrayal of the system's total life-cycle value.

Retrofit. The addition of a new technology to an existing building.

Primary Energy Production. Refers to the energy extracted from a given region of Canada through the production of crude oil (both conventional and synthetic), natural gas, natural gas liquids, coal, hydro-electricity and nuclear-electricity. Secondary energy consumption refers to energy actually consumed in a given region of Canada.

RSI. A measure of thermal resistance, or the tendency of a material to retard the flow of heat; the higher the RSI - value, the better the insulating quality of the material. RSI is the recipricol of a material's thermal conductivity or 1/Joules per second per m^2 per ^{o}C.

Thermal Mass. The potential heat storage capacity in a substance, system or building; usually used in reference to common building materials (concrete floors, masonry floors and walls, adobe walls) and passive designs (drum walls, Trombe walls).

Trombe Wall. A passive solar collector, named after the French designer Felix Trombe, features glazing through which the sun's rays travel and strike a large dark thermal mass, usually a thick concrete or masonry wall or water-filled barrels painted black. In the colder months, air in the space between glazing and mass is heated during the day. As it warms, the air rises through the top vent and flows into the living quarters. Cooler air that is near the floor of the living quarters is pulled into the air space to be heated. Throughout the day, this convective process continues. At night, the mass, which has stored a significant amount of thermal energy, releases heat into the living quarters via radiation. In the warmer months, the Trombe wall system can theoretically cool a building. Unfortunately, the wall itself tends to overheat and may add too much thermal energy to the structure if unwanted heat is not vented to the outside. In such cases, shutters or shades may have to be placed over the Trombe wall glazing in the summer.

Secondary Energy Consumption. Energy consumption at the end use for space heating, running appliances or automobiles as opposed to primary consumption for the production of higher level energy.

Watt. A unit of work or energy equivalent to 1/746 horsepower or the work done at the rate of one absolute joule (approximately 0.7375 foot-pounds or 10^7 ergs) per second.

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